ASPECTS OF TACTILE PERCEPTION
WITH DENTAL INSTRUMENTS

BY

COSIMO MAIOLO, B.D.S.

A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Dental Surgery in The University of Adelaide.

November, 1982

ERRATA AND AMENDMENTS

Page 3	Mis-spelling of "gauge"
Page 25	Measurement of hand tremors were done by Voight (1956) and referenced in Patkin's paper (1967).
Page 44	Mis-spelling of "instrumentation"
Page 112	Mis-spelling of "gauge"
Page 125	Mis-spelling of "gauge"
Page 126	Mis-spelling of "gauge"
Page 127	Mis-spelling of "finger"

DECLARATION

This thesis contains no material which has been accepted for the award of any degree or diploma in any university and to the best of my knowledge and belief, contains no material previously published or written by another person, excepting when due reference is made in the text.

C. Maiolo

ACKNOWLEDGEMENTS

Thanks are due to Dr. O. F. Makinson, Reader in the Department of Restorative Dentistry, The University of Adelaide and Dr. G. C. Townsend, Department of Oral Biology, The University of Adelaide, for their interest and assistance in the preparation of this report, and to Dentsply International for the supply of some of the probes used.

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PREFACE

This work was designed to define some of the parameters involved in the perception of surface roughness using some dental explorers, and to establish techniques for measuring the involved vibration waves. Because of the range of variables involved, the study was limited in extent and was planned to present the overall picture of the problem of tactile perception in dental practice.

Following on from this a separate study is currently being undertaken to measure tactile perception thresholds and vibration waves in selected dental hand instruments.

"The greatest sense in our body is our touch sense. It is probably the chief sense in the processes of sleeping and waking; it gives us our knowledge of depth or thickness and form; we feel, we love and hate, are touchy and are touched, through the touch corpuscles of our skin."

J. LIONEL TAYLOR,

The Stages of Human Life, 1921

SUMMARY

Selected aspects of tactile perception using dental explorers for examining surface roughness were evaluated. The following parameters were examined with the indicated methods of measurement for in vitro studies with forty-six operators (except for finger pressure with sixteen operators): (a) load applied on a tooth by an explorer (from strain - guage on a beam); (b) speed of moving the explorer (between electrical contacts in a plastic tooth); (c) load of the fingers on a simulated explorer handle (incorporating a strain - gauge on a beam); (d) instrument grip; (e) explorer preferences for sensitivity and handles for comfort. Tine stiffness of a series of explorers was found in vitro by load-deflection measurements. The effect of an explorer on tooth and other surfaces was examined under a scanning electron microscope; the enamel and dentine had been prepared by selected dental cutting instruments.

The results showed great variation between individuals in the way explorers are handled, and in instrument preferences: the load under the tip ranged from 2 gms to 266 gms with 43.5% of operators preferring to move the instrument laterally (to the right); the tip speed varied from 0.4 mm/sec to 9.3 mm/sec; the finger loads varied from 4.2 gms to 857 gms for the index finger, from 7 gms to 743 gms for the thumb and from

12.5 gms to 486 gms for the middle finger; to discriminate surface roughness stiff explorers were generally preferred and round handles; the areas, sites and tonicity of finger contacts on an explorer were also observed.

The explorer (with a "used" tip) cut into all prepared surfaces not following fine surface irregularities; on smooth perspex melting of the surface was evident with two vibration patterns.

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

1.1 GENERAL

Vision and tactile perception, usually through the medium of instruments, provides the dental operator with the information by which he assesses the conditions existing at surfaces.

Clinically, tactile perception is used to diagnose diseased tooth substance, assess surface roughness, check the form of cavity preparation, assess the retention and fit of restorations and to examine the occlusion of natural or artificial teeth.

Due to their mobility and their highly differentiated structure, the hands are the main organs that enable tactile exploration.

1.2 SCOPE

Published work relating to perception with dental instruments has been limited mainly to the use of dental explorers for diagnosis of caries (JACKSON, 1950; MILLER and ATKINSON, 1951; WILLIAMS et al, 1978; IWAKURA et al, 1978).

In recent years there has been some research into the development of a force controlled periodontal probe to standardise measurement of periodontal pockets (VAN DER VELDEN and DE VRIES, 1978; VITEK et al, 1979; POLSON et al, 1980).

There has been no published material relating to the mechanism of signal transmission or the testing of instruments to maximise perception of surface roughness.

The scope of this work was limited and intended to seek the parameters involved in using some dental explorers and to establish techniques for measuring the involved vibration waves.

1.3 FACTORS INVOLVED IN TESTING FOR SURFACE ROUGHNESS

The variables which affect the perception of a vibratory stimulus when using a dental explorer are listed (Fig. 1.1):

(1) SPECIMEN

material

roughness < amplitude / frequency

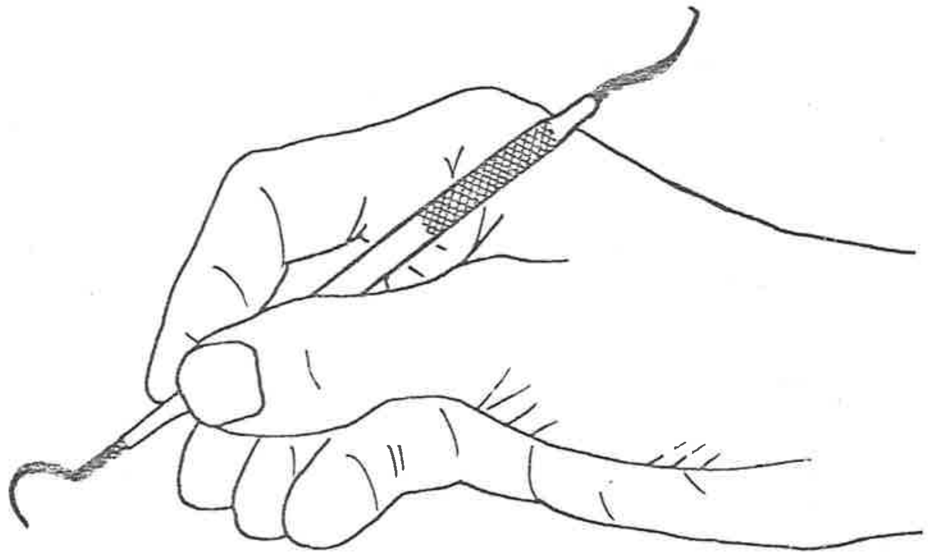
(2) EXPLORER

(a) Tine	(b) Handle
material	material
density	density
shape	shape
length	length
sharpness	weight
flexibility	size
	tine junction

(3) OPERATOR

(a) Clinical Factors	(b) Physiological Factors
load	skin impedance
direction	C.N.S. interpretation
speed	age
finger positions	disease
finger pressure	temperature
	fatigue
	drugs

The parameters selected for testing in this study are listed in the objectives (Chapter III).



SPECIMEN

material
roughness

amplitude
frequency

EXPLORER

(a) Tine

material
shape
length
density
sharpness
flexibility

(b) Handle

material
shape
length
density
weight
size
tine junction

OPERATOR

(a) Clinical Factors

load
direction
speed
finger positions
finger pressure

(b) Physiological Factors

skin impedance
CNS interpretation
temperature
experience
disease
fatigue
drugs
age

Fig. 1.1. Variables which affect the perception of a vibratory stimulus when using a dental explorer. (This diagram is repeated in Fig. 3.1 and 7.1 in order to clarify the appropriate sections of this work).

1.4 JUSTIFICATION OF THE PROJECT

The physical characteristics which maximise tactile perception with dental hand instruments have not been defined. For this work a series of tests were carried out to provide information on different aspects for selection and design of these dental instruments.

The need for this characterisation is illustrated by the following series of extracts relating to standards specifications by national and international bodies:

"At the Berlin meeting of TC 106 (the Dental Committee of the International Standards Organization), the Working Group on Dental Instruments did in fact draw up the draft on dental explorers but, ... we avoided trying to write down standards in the very area in which you are interested due to lack of data ...... I may say that the work could eventually be invaluable to TG 8 in adding to the existing basic standard some guidance on the testing for clinical use" (WATSON, 1981).

In the minutes of the sub-committee of the British Standards Institution relating to the preparation of the British Standard 2965:1970 for dental explorers, attention was drawn to the difficulty in the bending and rigidity tests where the tine tip of probes was very small (ROSENSTEIL, 1981).

A further two quotations describe the existing quality control for dental explorers in dental instrument manufacturing companies:

"Very little work has been done on this question of the part played by the flexibility, etc., of a dental explorer in clinical conditions. The majority of our products have to a large extent 'grown up like Topsy', and the satisfaction of the user has generally been the guide to manufacturing requirements" (WATSON, 1981).

"The reason that we consider these hollow-handle explorers to be more sensitive is that the lower total mass of the instruments permits vibration to be transmitted to the user's hand rather than absorbed in the mass of the handle. This phenomenon is substantiated more by individual preference than by test data but is one that our customers are convinced of" (GUTHRIE, 1981).

CHAPTER II

LITERATURE REVIEW

CHAPTER II

LITERATURE REVIEW

2.1 Dental Standards Relating to Dental Explorers

2.2 Surface Roughness

2.3 General Sensory Physiology: Psychophysics

Instrument factors
Speed

2.4 Instrument Grip

Effect of area of contact on vibration perception

2.5 Skin Impedance

2.6 Conclusion

2.1 DENTAL STANDARDS RELATING TO DENTAL EXPLORERS

The standards relevant to dental explorers are the British Standard BS2965:1970 (Australian Standard 1086: 1971) and the International Standard Draft ISO/DIS 7492.

BRITISH STANDARD BS 2965:1970 (AUSTRALIAN STANDARD 1086:1971).

This standard defines a dental probe as "a thin wire-like instrument with a sharp point, primarily designed for detecting dental caries. Its working end is defined as a 'tine' and may be carried by a stem or may join the shank directly".

The materials for the working ends of the instruments are either carbon steel or corrosion-resistant alloy. Designs and dimensions for the working end are displayed.

Probes are classified into three forms according to the thickness of the tine as either; thick, medium or thin.

They are graded according to their flexibility as rigid or flexible.

INTERNATIONAL STANDARD DRAFT ISO/DIS 7492

This standard defines the tine material as either austenitic stainless steel or martensitic stainless steel. Values for hardness and tensile strength are outlined for different steel grades used for the working end. Designs and dimensions for the working end are displayed.

Neither standard covers a number of factors which could be expected to affect the transmission of tactile perception to the fingers. A comparison with the probable variables (Section 1.3) shows that the standards are very limited, as both place emphasis on tine shapes and definitions, and the British Standard also directs attention to tine flexibility.

2.2 SURFACE ROUGHNESS

Volschansky, et al (1974), stated that there is a problem in the interpretation of the term roughness of cavity preparations and that an objective definition should be developed.

Much earlier, Lammie (1957) had used a surface analyser to measure the surface roughness of tooth surfaces resulting from cuts made with various low speed rotary dental instruments. He preferred to calibrate the instrument to measure the root mean square value (R.M.S.) rather than the arithmetic mean. The value obtained for a carborundum disc was 1.0 µm and for a diamond cylinder (No. 25 Starlite) 3.0 µm.

Concurrently Charbeneau, et al (1957), used a similar instrument (Proficorder) where their results for a carborundum disc were 1.5 µm and for various sizes of diamond points for the low speed there was a range from 18 to 50.8 µm.

In general, profiling instruments are useful only where the surface is uniform in its properties since it is assumed that the profile is representative of the surface as a whole (Australian Standard 1965 - 1977).

Following the introduction of the high speed turbine handpieces, finer diamond particle instruments and tungsten carbide burs came into use for cavity preparation. Some of the main research projects used new examination techniques. Boyde and Knight (1969), Boyde (1975), illustrated the potential for the use of the scanning electron microscope (S.E.M.) to study the result of conventional techniques of cavity preparation. Eick, et al (1970), also used the S.E.M. to observe the topography of cut tooth surfaces and concluded that the surfaces cut with a diamond instrument were rougher than those cut with a carbide bur. Again Kanter, et al (1980), used the S.E.M. to compare the surface roughness of composite restorative resins finished with various polishing agents.

Meyer and Lie (1977), used the combination of a surface analyser and an S.E.M. to study root surface roughness resulting from the use of a hand curette, an ultrasonic curette and rotating diamond or scaler points in the removal of calculus.

2.3 **GENERAL SENSORY PHYSIOLOGY: PSYCHOPHYSICS**

The neurophysiological and neuro-anatomical aspects of tactile perception and vibration damage to tissue were reviewed in detail (MAIOLO, 1981) prior to experimental data collection phases of this work.

The parameters involving touch and vibration perception are the subject of a seperate research project currently being undertaken.

Instrument Factors

Since during dental procedures instruments are used as extensions of the fingers, it is conceivable that the instrument itself will affect tactile perception.

Such factors as the type of material, the shape, the design and the sharpness of the instrument should all affect the transmission of information through it. However no documentation of these effects has been reported in the literature.

With reference to medical instruments Patkin (1980) has suggested that for optimum results from medical instruments, the instruments should be well cared for and maintained in good condition.

Speed

Katz in 1925 experimented with subjects using their index finger to determine surface roughness. His results demonstrated that during the procedure subjects did not maintain a constant speed. His conclusions were that if as a result of moving the hand faster across the surface a higher "pitched" vibration was produced, then in order to maintain a constant impression of a surface at varying hand speeds, the subject needs to simultaneously judge the "pitch" and hand speed (KREUGER, 1970).

2.4 **INSTRUMENT GRIP**

DENTAL PROCEDURES

According to the finger positions used to grasp dental handpieces, Makinson and Hume (1982) classified instrument grips into three categories:

Type A - contact with the palmar surface of the thumb and index finger and the lateral surface of the middle finger at the same axial position of the instrument: the traditional pen grasp (Fig. 2.1).

Type B - contact with the palmar surface of the thumb and index finger at the same axial position but with the palmar surface of the middle finger close to the working point (Fig. 2.2).

Type C - all other types of grip (Figs. 2.3, 2.4, 2.5).

Early authors were interested in hand instrument grips which demonstrated cutting efficiency in relation to the force applied. For the traditional pen grip (Type A), Black (1917) noted three subgroups according to the precise lateral area of the middle finger contact. He also made measurements of the force that could be generated and instrument control, from which he concluded that the Type B grip (as described previously) had an advantage over other grip types for hand use (Makinson and Hume, 1982). Gabel (1940) also preferred

Fig. 2.1. Type A hand grip (MAKINSON and HUME, 1982).

Fig. 2.2. Type B hand grip (MAKINSON and HUME, 1982).

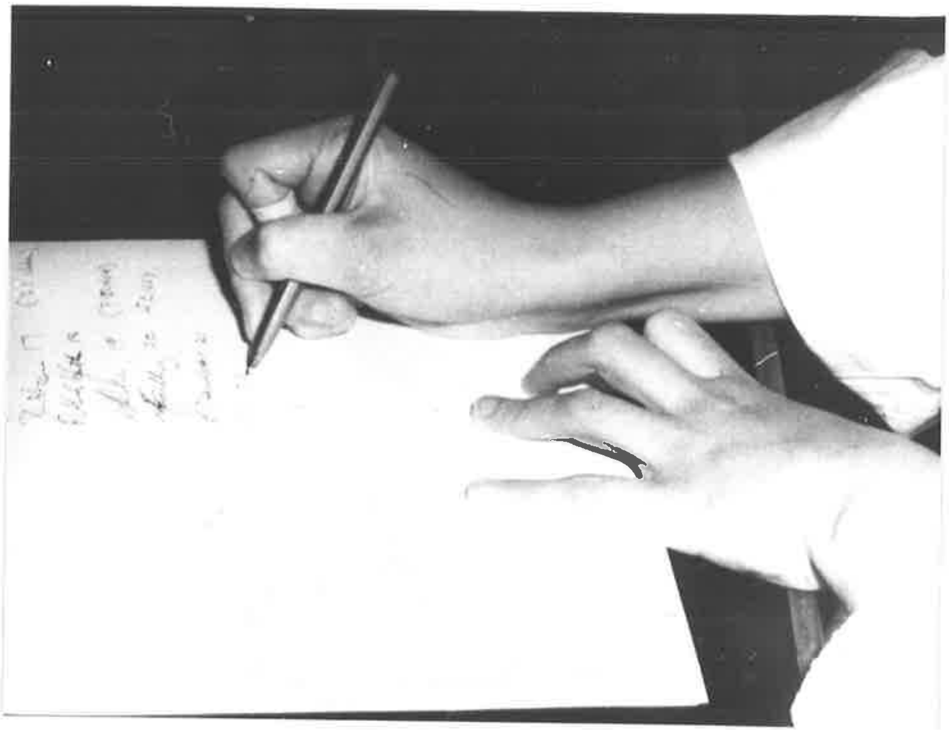


Fig. 2.3. Type C hand grip
(MAKINSON and HUME, 1982).

Fig. 2.4. Type C hand grip
(MAKINSON and HUME, 1982).

Fig. 2.5. Type C hand grip
(MAKINSON and HUME, 1982).

the Type B grip from the point of view of force application to the working tip of hand instruments.

McGee (1937) described a Type A grip where the power source was the index finger and thumb, while the middle finger acted as a fulcrum, and also a Type B grip where the source of power was from the middle finger whilst the index finger and thumb stabilised the instrument and the ring finger served as a rest. In 1967, Gilmore also favoured a grip similar to the Type A described by McGee.

Of the more recent authors, Barton et al (1968), Bell and Grainger (1971), Charbeneau et al (1981), and Baum, Phillips and Lund (1981), all described and or recommended grips of the Type B. Only Beach (1973), has provided a detailed description of the contacting finger surfaces which were related to series of grips of the Type A.

Makinson and Hume (1982), related clinical performance of dental students to preferred instrument grip. They found that for a dental handpiece, the grip most preferred by the students was the Type B, and that there was no difference in clinical performance between students using either grips A or B. However, they did demonstrate that students using unusual handpiece grips (Type C) tended to be those students in the lower clinical grades.

MEDICAL PROCEDURES

Five types of instrument grip have been described for general surgical procedures by Patkin (1969). Three of these are functional grips called the power grip (as for a hammer), the external precision grip (as for a pen), and the internal precision grip (as for a knife). The two remaining grips are storage grips which he terms the ulnar storage grip and the suture storage grip. For the precision grip Patkin outlines the importance of the "patch of skin near the apex of the cleft between the thumb and index finger over the second metacarpal bone or its adjoining phalanx", which he feels helps to steady the instrument.

Patkin (1967), also stresses the control of hand tremor during surgical procedures, and states that the unsupported arm oscillates 7 to 20 times per second with a movement of 0.5 to 3.0 mm. In addition he lists a multitude of factors which can affect this tremor.

EFFECT OF AREA OF CONTACT ON VIBRATION PERCEPTION

The sensitivity to vibration depends strongly on the areal extent of a stimulus. In relation to the perception of different vibratory frequencies, Geldard in 1940 noted that larger contacting media gave smaller threshold values when lower frequencies were used. Later studies by Verrillo (1963, 1966 a and b) concluded that the vibratory threshold does not vary with frequency when a small enough vibrator is used.

Sensitivity curves for different contactor areas are shown in Fig. 2.6. For large stimulus areas, sensitivity decreases with frequency for stimulus frequencies below 250 Hz; the increase in threshold totalling 12 decibels for every doubling of frequency. Above frequencies of 250 Hz, the sensitivity decreases at a rate of 9 decibels per doubling. For very small stimulus areas (less than 1 square mm), a flat curve results, the sensitivity remaining constant with relation to stimulus frequency over the range of 25 to 700 Hz.

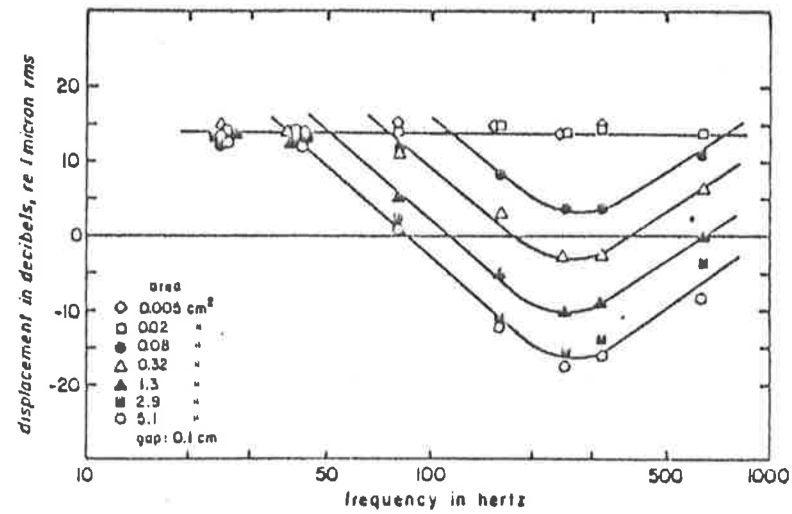


Figure 2. 6 Relative tactile sensitivity (absolute threshold) to different vibration frequencies. When the stimulator has an area 1 mm² or greater, sensitivity is greatest near 250 Hz. When the stimulator is smaller, sensitivity hardly varies with frequency.

(Verrillo, 1963)

2.5 SKIN IMPEDANCE

The mechanical impedance of the skin influences the selective transmission of vibrational stimuli to the receptors. Damping in the skin is caused by friction which results in the transformation of part of the stimulus energy into non-specific thermal energy. This mechanical impedance functions as a filter and affects both the stimulus frequency and the phase angle between stimulus and adequate receptor displacement. Because different and distinct tissue types make up the total transmitting system, (for example, subdermal fatty tissue, bone, collagen-rich cutis, muscle, skin) the transmission of vibrational stimuli is not restricted to just one homogeneous medium. Therefore a great variation exists in the impedance between different combinations of tissue types (Fig. 2.7).

Von Bekesy in 1939, was one of the first researchers to attempt to measure the mechanical impedance of the skin (KEIDEL, 1968). He restricted his calculations to the frequency range from 0.5 to 100 Hz and found that the numerical values which he obtained were dependant upon the site of vibration. Fig. 2.8 illustrates the data obtained by Von Bekesy for the skeletal muscles of the extremities in a sitting human subject. The conclusions derived from this complex impedance were as follows: the resonance frequency (mass and elasticity components of the complex impedance

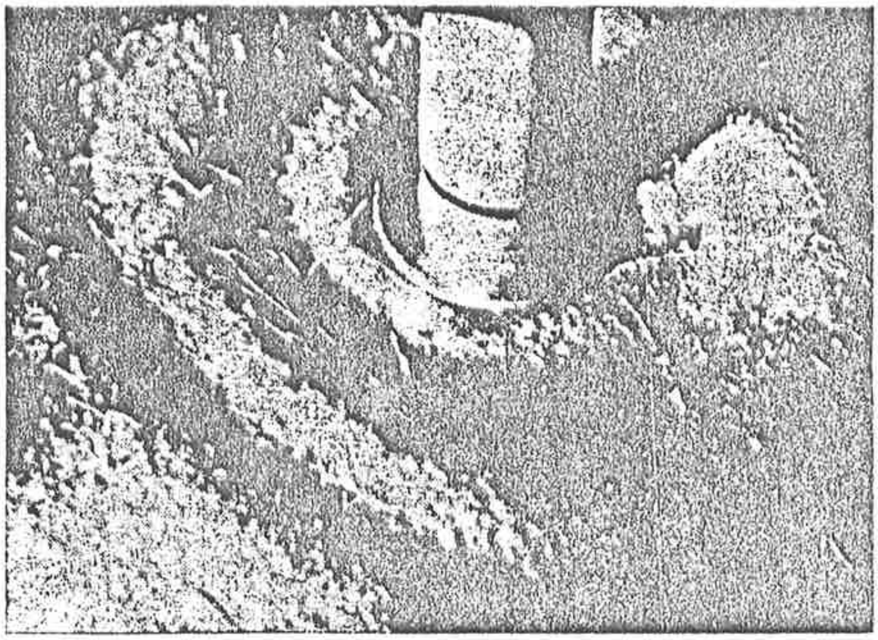


Fig. 2. 7 **Record of traveling waves due to sinusoidal vibrations of 64 cps on the thigh of man (stroboscopic illumination) (Franke, von Gierke *et al.*, 1951).**

(Keidel, 1968)

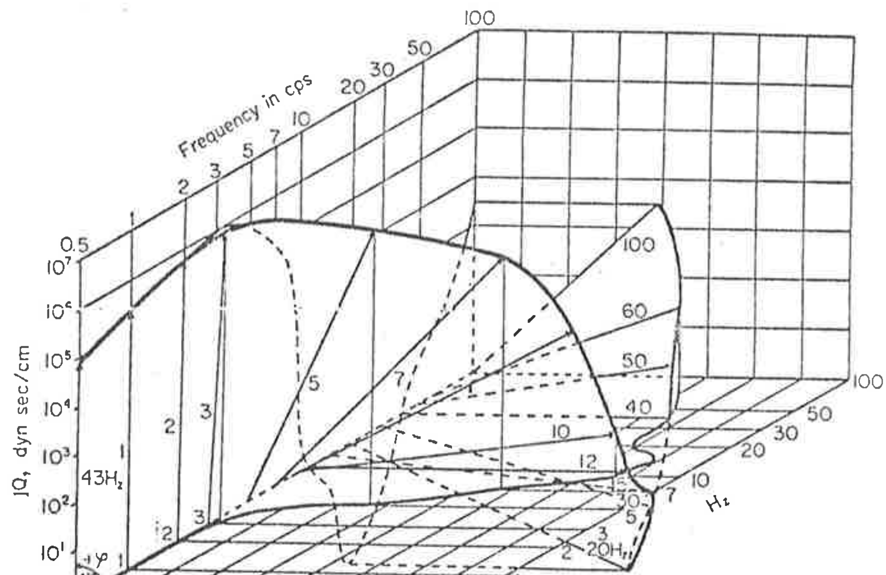


Fig. 2. 8 Three-dimensional diagram of the mechanical impedance of the human body to sinusoidal vibrations. Abscissa, real part of the complex impedance; ordinate, imaginary component (Keidel and Schmitt, 1955, based on data of von Békésy, 1939).

(Keidel, 1968)

are equal) occurs at frequencies of around 40 Hz and 12 Hz; under these test conditions the human body acts like an elastic spring in the frequency range from 12 to 38 Hz; for frequencies below 12 Hz the mass character of the complex impedance becomes evident and tends to increase down to a frequency of 3 Hz; and finally in the low frequency range from 3 Hz down to 0.5 Hz the human body behaves as an inert mass (KEIDEL, 1968).

In later studies undertaken by Franke and von Gierke in 1951, the frequency range was extended up to one megacycle. Their results demonstrated that for very high mechanical frequencies, the human body mimics a mass plus a frictional resistance (Fig. 2.9) (KEIDEL, 1968).

For the standing and sitting human subject Coermann (1938, 1939, 1940) and Dieckmann (1957, 1958) both made independant measurements of the resonance frequencies and the total complex impedance. Both investigators were in agreement that in man the most important resonance frequency is in the region of 3 Hz (KEIDEL, 1968).

In 1927, Franke equated the propagation of travelling waves in the skin to those in the walls of arteries and in the cochlea of the ear. He subsequently derived a complex formula to calculate the propagation velocity of these waves. However this formula was more suited for arterial waves than for travelling waves within the skin. Oestreicher (1951) derived a new

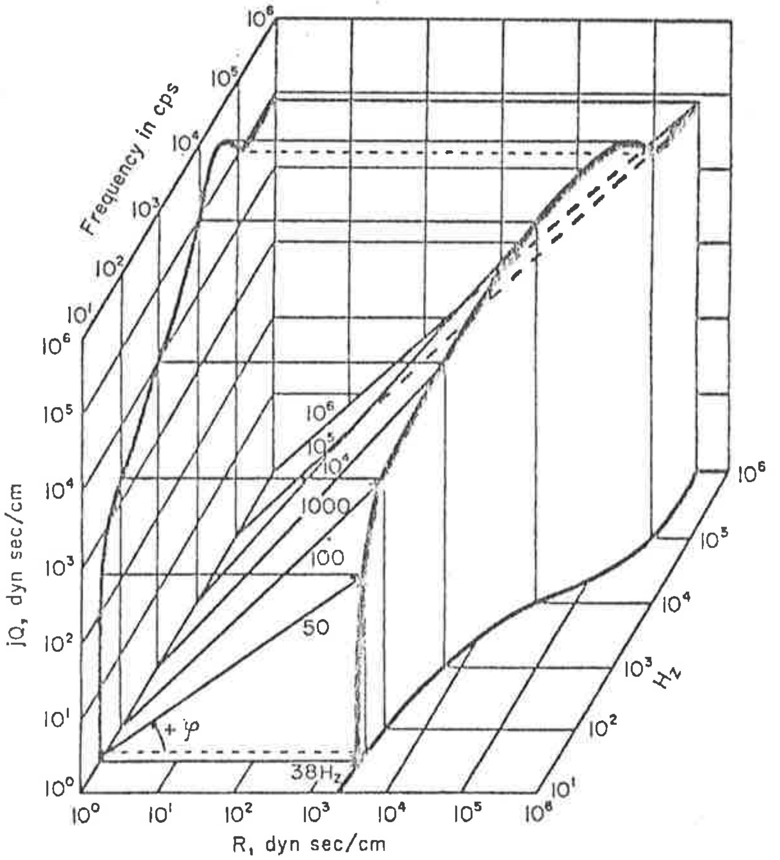


FIG. 2.9 Mechanical impedances as in Fig. 13 but for higher frequencies up to 10^6 cps (Keidel and Schmitt, 1955, based on data of Franke *et al.*, 1951).
(Keidel, 1968)

TABLE 2.1 (Keidel, 1968)

	Tissue beneath skin			
	Fat	Muscle relaxed	Muscle under tension	Bone
Shearing waves	4.9×10^3	1.44×10^4 7.84×10^4 0.20×10^4	2.71×10^5 2.71×10^5 4.23×10^5	$>1 \times 10^6$
Rayleigh waves	6.1×10^3	1.78×10^4 9.68×10^4 0.25×10^4	3.34×10^5 3.34×10^6 5.22×10^5	$>1.24 \times 10^6$

[a] All values are given in dynes per square centimeter.
[b] Shearing waves of the skin should not be confused with Rayleigh waves, the propagation velocity of which can be calculated easily by multiplying the propagation velocity of the shearing waves by 0.91. The elasticity coefficient for Rayleigh waves equals $c^2 \cdot \rho$ divided by 0.81.

formula for the calculation of the velocity of skin waves (KEIDEL, 1968). Essentially Oestreicher regards the skin as being a homogeneous elastic medium distinguished by the following four physical constants: (1) the shearing elastic modulus; (2) the shearing viscosity coefficient; (3) the modulus of volume compressibility, and (4) the coefficient of volume viscosity (KEIDEL, 1968).

Apart from shearing waves, compression waves can also be noticed on the skin. However, damping of the shearing waves occurs to a much greater extent than does damping of the compression waves which results in localisation of the shearing waves to the skin surface adjacent the source of vibration. With increasing frequency the areal extent of the shearing waves is decreased whereas compression waves travel to greater distances from the source of vibration. Since the perception of vibration occurs within a relatively low-frequency band width, the propagation velocity of the shearing waves can be considered to be dependant only on the shearing elasticity coefficient. Calculations of the dynamic shearing elasticity coefficient of the human skin with respect to the site of vibration have been made by Keidel (1968) (Table 2.1). The location of the vibratory stimulus affects both the dynamic shearing elasticity coefficient and the wave velocity to the extent that even the type of tissue underlying the skin surface will bring about a change in these values.

Shearing waves maintain the same amplitude at any depth. These differ from Rayleigh waves only in that Rayleigh waves demonstrate a decrease in amplitude with increasing depth, and therefore a difficulty exists in the differentiation of these two wave types in the human skin. Keidel (1968) believes that oscillation of the skin itself occurs in a shearing wave pattern, whilst the underlying tissues vibrate mainly in a Rayleigh wave pattern. Hence the "true" integral value for the shearing elasticity coefficient of the skin should lie somewhere between that for shearing and that for Rayleigh waves.

Apart from the elasticity coefficient of the underlying tissue, the propagation velocity of travelling waves in the human skin is also dependant on other factors such as the frequency of vibration, skin temperature and the skin blood supply. The effect of frequency is that an increase in the frequency of vibration results in a shift from the shearing and Rayleigh wave types to that of compression waves. Accordingly, for mechanical vibrations in the skin there is a variation in both the wavelength and wave velocity, the result of which is a considerable scattering of the travelling waves (Fig. 2.10).

Table 2.2 outlines values for sinusoidal vibrations obtained by Keidel (1968). The range of propagation velocity in the human skin is from 70 to 1,000 cm/sec.

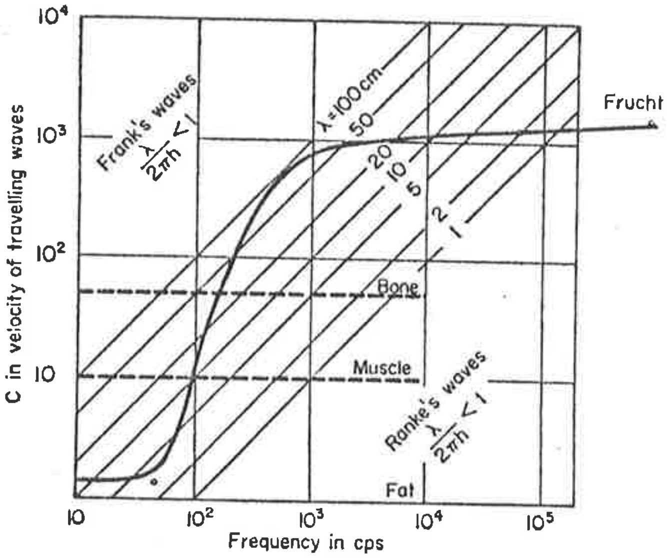


FIG. 2·10 Dispersion of the velocity of traveling waves along the skin in man based upon data of Franke *et al.* (1951) (open cycle) and Frucht (1952, 1953) (solid line) according to Keidel (1956). The dispersion reveals three types of waves in the skin and the tissue beneath: shearing waves, Rayleigh waves (low velocities), and compression waves (high velocities).
(Keidel, 1968)

TABLE 2.2 (Keidel, 1968)

	Epigastrium		Relaxed skeletal muscle		Muscle under tension		Bone	
	$\lambda/4$ (cm)	c (cm/sec)	$\lambda/4$ (cm)	c (cm/sec)	$\lambda/4$ (cm)	c (cm/sec)	$\lambda/4$ (cm)	c (cm/sec)
Numerical value of data	0.35	70	1.4	280	2.6	520	5	1000
			0.6	120	2.6	520		
			2.25	450	3.25	650		

c = propagation velocity

The lowest velocity was found in skin above fatty tissue whilst the highest velocity occured in the skin above bone. Substitution of sinusoidal vibrations for vibrations by mechanical pulses resulted in higher propagation velocities in the range between 7 and 450 metres/sec.

2.6 CONCLUSION

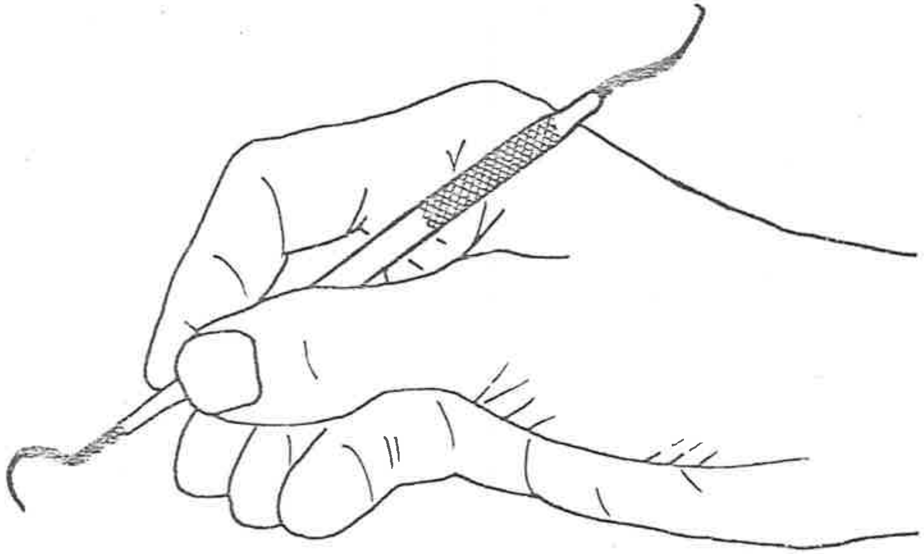
Most of the research impetus has been concentrated on the physiology of the sensory system.

Aside from instrument grip, no documentation was found which defines the clinical parameters for the use of dental hand instruments.

Furthermore, no documentation was found in relation to the mode of transmission of tactile perception through hand instruments.

CHAPTER III

OBJECTIVES OF THE STUDY



SPECIMEN

- material
- roughness
  - amplitude
  - frequency

EXPLORER

(a) Tine

- material
- shape
- length
- density
- sharpness
- flexibility

(b) Handle

- material
- shape
- length
- density
- weight
- size
- tine junction

OPERATOR

(a) Clinical Factors

- load
- direction
- speed
- finger positions
- finger pressure

(b) Physiological Factors

- skin impedance
- CNS interpretation
- temperature
- experience
- disease
- fatigue
- drugs
- age

Fig. 3.1. Variables which affect the perception of a vibratory stimulus when using a dental explorer.

CHAPTER III

OBJECTIVES OF THE STUDY

The variables which affect the perception of a vibratory stimulus when using a dental explorer are outlined in Fig. 3.1.

As listed below particular variables were selected for study relating to mechanical tactile contact and sensory perception. It was necessary to preface the main work by a pilot study relating to prepared surfaces.

1. Pilot Study:

   To measure the surface roughness produced on a set of prepared surfaces of enamel and dentine with a series of cutting instruments.

2. Mechanical Aspects of Explorer Use:

   2.1 To determine the effect on tooth structure and some restorative materials, of probing for surface roughness.

   2.2 To observe explorer tine tip wear following use on enamel and dentine surfaces.

   2.3 To compare methods of characterising tines mechanically (stiffness).

3. Clinical Aspects of Explorer Use:

   3.1 To determine the average conditions of use of dental explorers when testing for surface roughness in terms of:

3.1.1 load applied to tine

3.1.2 speed of tine movement

3.1.3 finger loads on explorer handles

3.2 Instrument Grip:

To assess -

3.2.1 type of grip

3.2.2 area of grip

3.2.3 tonicity of the tissue contact areas.

4. Clinical Preferences:

4.1 To seek operator preferences in explorers for determining surface roughness.

4.2 To seek operator preferences in explorer handles for handle comfort.

CHAPTER IV

PILOT STUDY

CHAPTER IV

PILOT STUDY

In this work a pilot study for surface roughness and sixteen parameters in the main programme are described; for clarity each is presented as an entity with methodology, results and discussion.

4.1 OBJECTIVES

The purpose of this study was to measure the surface roughness of prepared surfaces of enamel and dentine from a series of cutting instruments.

Subsequently surfaces were selected of known roughness values for the later studies of perception thresholds, operator preferences and vibration transmission.

4.2 MATERIALS AND METHODS

Extracted permanent teeth, which had been stored in a ten per cent formalin solution, were hand held while cuts were made along dentine and enamel surfaces in one direction only. Tooth specimens were prepared using the following:

1. Star No. 701 7P tapered fissure diamond*, Fis L20 tapered fissure diamond** and Hi Di SF2 flat fissure diamond*** in an air

* Star Dental, A Syntex Dental Co., U.S.A.
** Finzler, Schrock and Kimmel, Bad Ems.
*** A.D. International Co., London

turbine handpiece with water spray at 300,000 r.p.m.

2. Tungsten carbide Komet H21E flat fissure bur+ in a turbine handpiece with water spray at 300,000 r.p.m.

3. Carborundum disc++, 3M medium grade disc+++, and 3M fine grade disc+++ in a handpiece at 20,000 r.p.m.

A surface analyser* was used to measure the surface roughness on the prepared enamel and dentine surfaces. Measurements were taken both along and across the grain of cut. The stylus tip radius was 0.0005 inches (12.5 μm) and the instrument was calibrated to measure the roughness (Ra) value (called arithmetic average A.A. or centre line average C.L.A.) (LEITAO and HEGDAHL, 1981) and the cut off value was 0.8 mm.

Selected specimens were examined under the scanning electron microscope (S.E.M.).

The standard surface roughness blocks used for comparison with the prepared tooth specimens were Rugotest 101 and Rugotest 104 Surface Finish Specimen L.C.A. blocks**.

+ G.E.B.R. Brasseler GmbH Co. K.G., Lemgo
++ Ainsworth Co., Sydney, Australia
+++ 3M Co., Dental Products Division, St. Pauls, USA
* Mitutoyo Surftest III, Mitutoyo MFG, Co., Japan
** Pierre Roch, Rolle, Switzerland

4.3 RESULTS

The Ra surface roughness measurements recorded are given in Table 4.1. Values for the standard Rugotest plates are given in Figs. 4.1 and 4.2.

Photomicrographs of tooth specimens cut with a H21E tungsten carbide bur and Star diamond No. 701 7P bur are shown in Figs. 4.3 and 4.4.

4.4 DISCUSSION AND CONCLUSIONS

The cutting instruments used were selected to represent a graduation in the degree of surface roughness which results when various instrument types are used during clinical procedures. The surface roughness values obtained (Table 4.1) confirm this graduated difference. Of the instruments used, the 3M fine grade disc produced a surface which had the lowest Ra value measurement, hence the smoothest surface.

It is not possible to make direct comparisons between these results and those of Lammie (1957) and Charbeneau (1957). This is because of the differing techniques and intrumentation in addition to variation in surface analyser calibration. Nevertheless the results obtained for a carborundum disc and some grades of diamond instruments do show a similarity with those of these earlier investigators.

Test surfaces from the precision Rugotest plates can be selected which relate in roughness to the values obtained on the prepared enamel and dentine surfaces. This allowed the substitution of a standard surface roughness Rugotest Block for dentine and enamel specimens in vibration and perception studies.

The advantages of using a metal plate over tooth specimens for studies involved with tactile perception are:

1. a greater surface area for experimentation is available
2. uniformity of surface roughness
3. replacement of worn or degraded test surfaces
4. availability of the same test ("absolute identical") surfaces to other workers as the precision plates are formed by electro-plating from master dies.

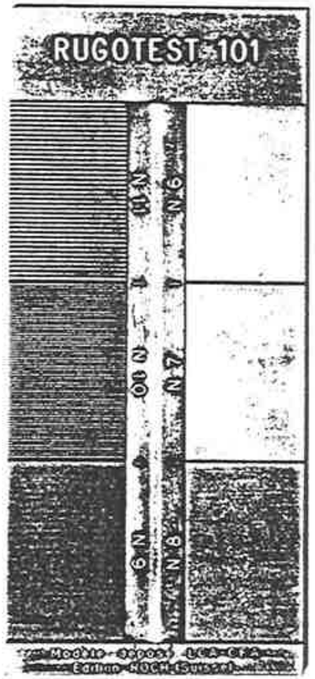
Photomicrographs allow visual assessment of the topography of dentine and enamel surfaces, a method used by Boyde and Knight (1969), Eick, et al (1970), Boyde (1975), Myer and Lie (1977) and Kanter, et al (1980).

Of the thirty two photomicrographs made, three are included (Figs. 4.3 and 4.4) to show how the S.E.M. can be used as an indication that a surface has the same overall roughness, and secondly, the potential for direct measurement of topographical features in terms of ridges per millimeter for initiating vibration in sensing instruments.

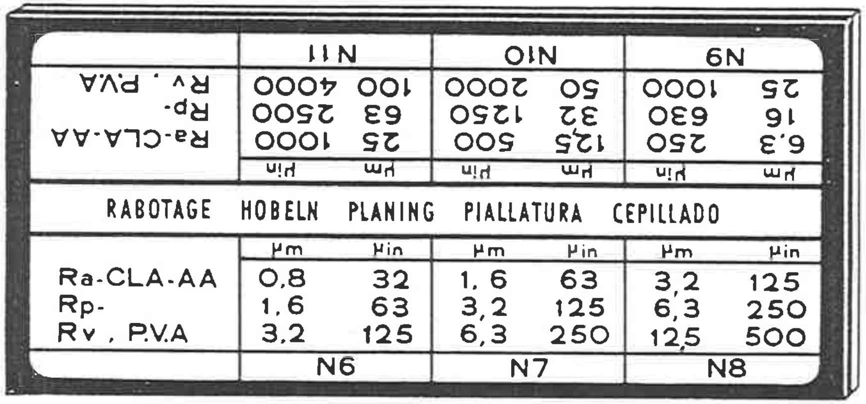
TABLE 4.1. Ra Roughness Values (in μm)

		Komet H21E W. Carbide bur	Star 701 7P diamond	Fis L20 diamond	Hi-Di SF2 diamond	Carborundum disc	3M medium disc	3M fine disc
ENAMEL	measured across grain of cut	8.7	7.6**	3.9**	2.9**	2.2**	0.63**	0.35**
	measured along grain of cut	1.1	4.0**	2.7**	1.6**	1.0**		
DENTINE	measured across grain of cut	4.0	7.2**	2.7**	2.9**	2.1**	0.59**	0.29**
	measured along grain of cut	0.75	3.8**	2.2**	2.0**	0.8**		

** represent the average measurement of readings from two specimens.
(cut off value = 0.8 mm)



RUGOTEST 101 : Block reduced to scale
Full size 4" X 2" of block only



	N11		N10		N9	
	μm	μin	μm	μin	μm	μin
Ra-CLA-AA	25	1000	12,5	500	6.3	250
Rp-	63	2500	32	1250	16	630
Rv . P.V.A	100	4000	50	2000	25	1000

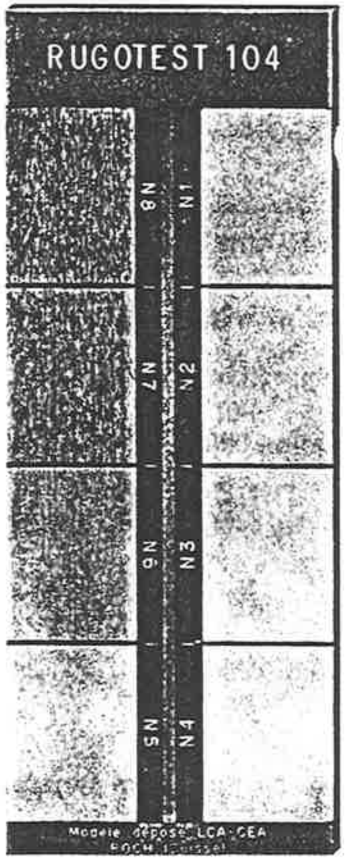
RABOTAGE HOBELN PLANING PIALLATURA CEPILLADO

	μm	μin	μm	μin	μm	μin
Ra-CLA-AA	0,8	32	1, 6	63	3,2	125
Rp-	1, 6	63	3,2	125	6,3	250
Rv , P.V.A	3,2	125	6,3	250	12,5	500
	N6		N7		N8	

RUGOTEST 101 : Reverse face of the block giving nominal surface finish values in the three systems : Ra, Rp and Rv, for French and Swiss types only.

Type	Classification						Order reference
Anglo-American*	1000	500	250	125	63	32	RUG 101 A
French*	19	18	17	16	15	14	RUG 101 CF
Swiss*	N 11	N 10	N 9	N 8	N 7	N 6	RUG 101 CS

Fig. 4.1. Surface roughness values for Rugotest block No. 101.



Full size 5" × 2" of block only

	N5		N6		N7		N8	
	μ m.	μ in.	μ m.	μ in.	μ m.	μ in.	μ m.	μ in.
Ra, CLA, AA	0,4	16	0,8	32	1,6	63	3,2	125
Rp	0,8	32	1,6	63	3,2	125	6,3	250
Rv, P.V.A	2,5	100	5	200	10	400	20	800

Rectification plane - Planschleifen - Surface grinding
Rettifica in piano - Rectificacion plana

	μ m.	μ in.	μ m.	μ in.	μ m.	μ in.	μ m.	μ in.
Ra, CLA, AA	0,025	1	0,05	2	0,1	4	0,2	8
Rp	0,05	2	0,1	4	0,2	8	0,4	16
Rv, P.V.A	0,16	6,3	0,32	12,5	0,63	25	1,25	50
	N1		N2		N3		N4	

RUGOTEST 104: Reverse face of the block giving nominal surface finish values in the three systems: Ra, Rp and Rv, for French and Swiss types only.

Type	Classification								Order reference
Anglo-American*	125	63	32	16	8	4	2	1	RUG 104 A
French*	16	15	14	13	12	11	10	9	RUG 104 CF
Swiss*	N 8	N 7	N 6	N 5	N 4	N 3	N 2	N 1	RUG 104 CS

Fig. 4.2. Surface roughness values for Rugotest block No. 104.

Fig. 4.3.
Photomicrograph of an enamel surface cut with a H21E tungsten carbide bur. x36.

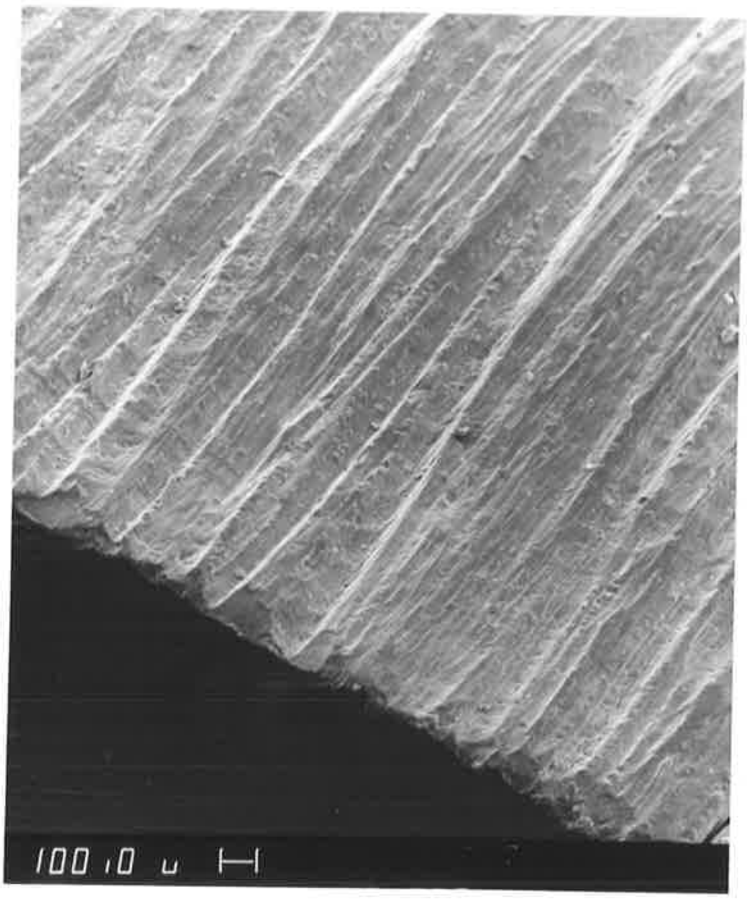


Fig. 4.4A.
Photomicrograph of a dentine surface cut with a Star 701 7P diamond bur. x36.

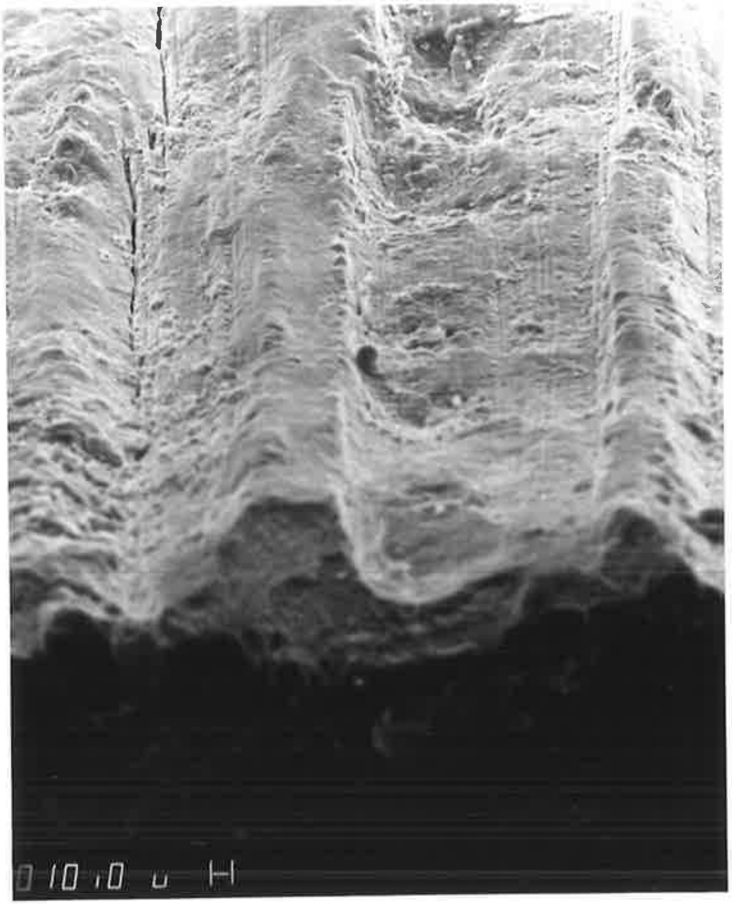


Fig. 4.4B.
Photomicrograph of a dentine surface cut with a Star 701 7P diamond bur. x180.

IN SUMMARY

1. Metal Rugotest plates provided standardised test surfaces in the range of roughness produced by clinical instrumentation on enamel and dentine. Hence surfaces of known roughness value were selected for later studies of perception threshold, operator instrument preferences, and vibration transmission.
2. The S.E.M. by its clarity in depth of field allowed the overall assessment of surface roughness of specimens and was selected as the method for later examining explorer tine effects on tooth surfaces.

CHAPTER V

MECHANICAL ASPECTS

CHAPTER V

MECHANICAL ASPECTS

5.1 THE EFFECT OF AN EXPLORER USED ON TOOTH AND OTHER SURFACES:

5.1.1 MATERIALS AND METHODS

A used American Dental Amflex I sickle explorer* was passed over selected surfaces as for detecting surface roughness. These surfaces were as follows:

1. Enamel: from a tooth which had been stored in a ten per cent formalin solution and was prepared using a carborundum disc at 20,000 r.p.m.
2. Dentine: from a tooth which had been stored in a ten per cent formalin solution. The surface was prepared by three methods:
   - (a) using a carborundum disc at 20,000 r.p.m.
   - (b) using a Fis L20 tapered fissure diamond bur in an air turbine handpiece with water spray at approximately 300,000 r.p.m.
   - (c) using a Star No. 701 7P tapered fissure diamond bur in an air turbine handpiece with water spray at approximately 300,000 r.p.m.

* American Dental Manufacturing Co., Missoula, Montana, U.S.A.

In addition to the dental explorer being passed over surfaces (b) and (c) above, the profilometer stylus was passed over these surfaces as if to obtain a surface roughness recording.

3. Amalgam: Tytin* before polishing and also after polishing to a clinical standard.
4. Metals: brass and Ticon** as manufactured.
5. Composite resin: Adaptic*** as from a matrix strip.
6. Microfilled resin: Heliosit++, Durafil+++ and Visiodispers++++ as from matrix strips.
7. Perspex: as manufactured.

Each surface was subsequently examined under the scanning electron microscope. The perspex specimen was also examined under an optical microscope.

* S.S. White, U.S.A.
** Ticonium Co., U.S.A.
*** Johnson and Johnson, U.S.A.

++ Ivoclar, Vivadent Schaan/Liechetenstein
+++ Kulzer Co., West Germany
++++ Espe GmbH, West Germany

Fig. 5.1.
Photomicrograph of enamel as prepared by a carborundum disc. x180. Arrows outline the area traversed by an American Dental Amflex I sickle explorer.

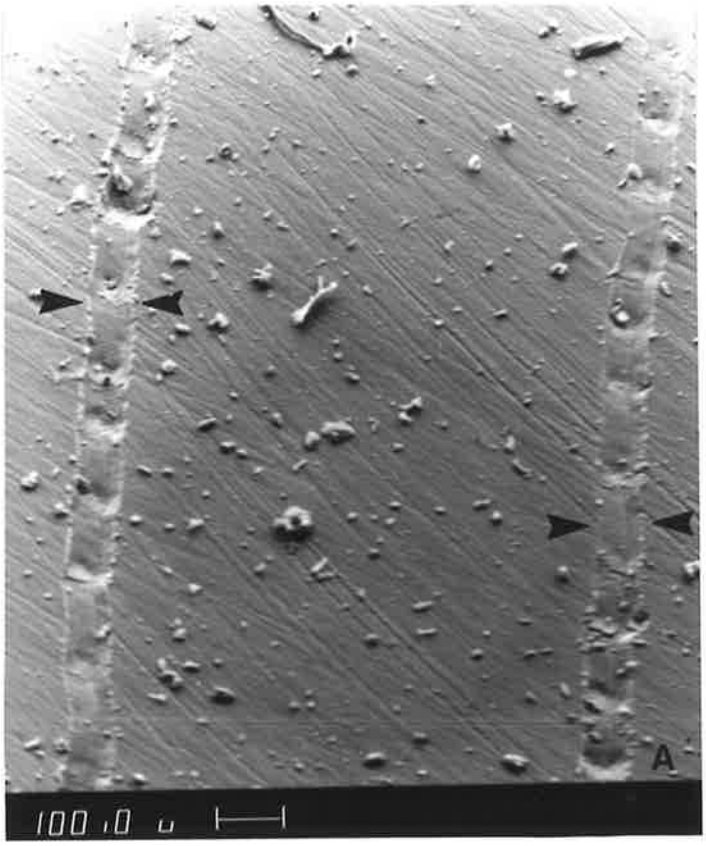
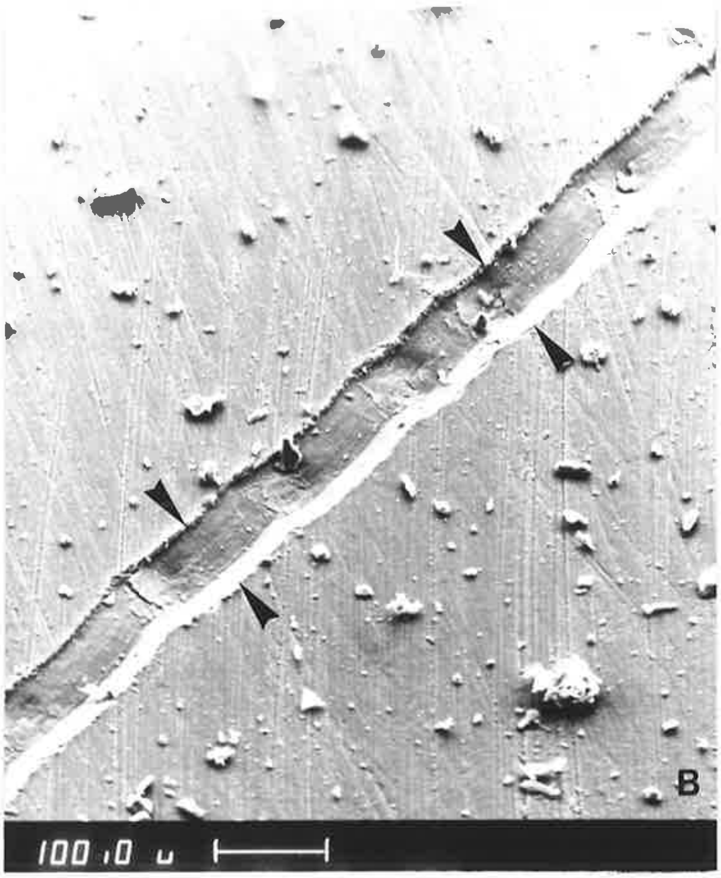


Fig. 5.2. A, B
Photomicrograph of the effect of an American Dental Amflex I sickle explorer on dentine as prepared by a carborundum disc
A x72, B x126.
Arrows outline the area traversed by the explorer.



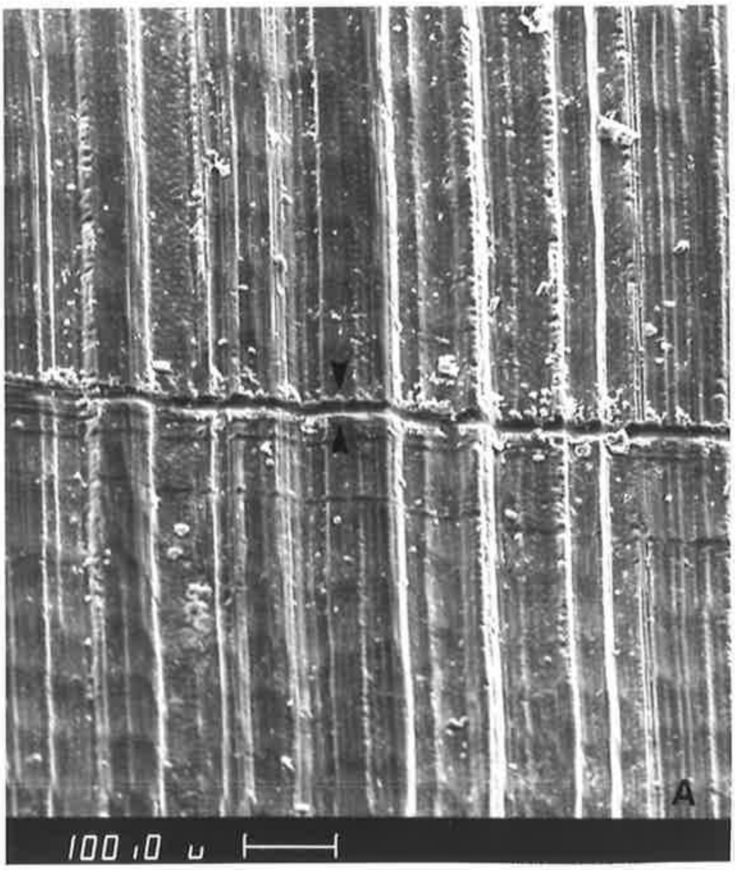
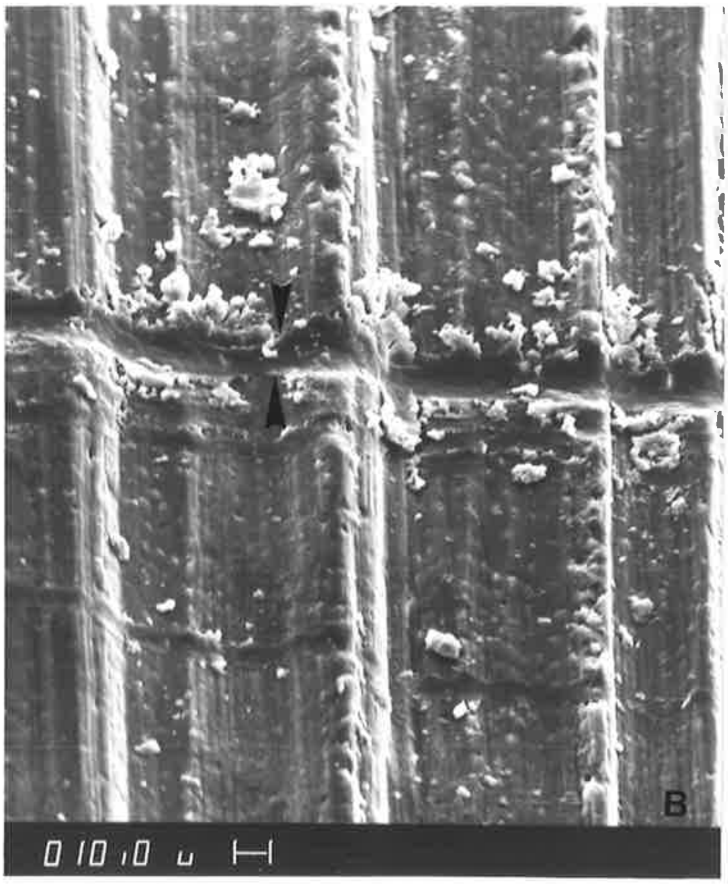


Fig. 5.3. A, B Photomicrographs of the effects of a profilometer stylus on a dentine surface prepared using a Fis L20 diamond bur.
A x108, B x360.
Arrows delineate profilometer tracks.



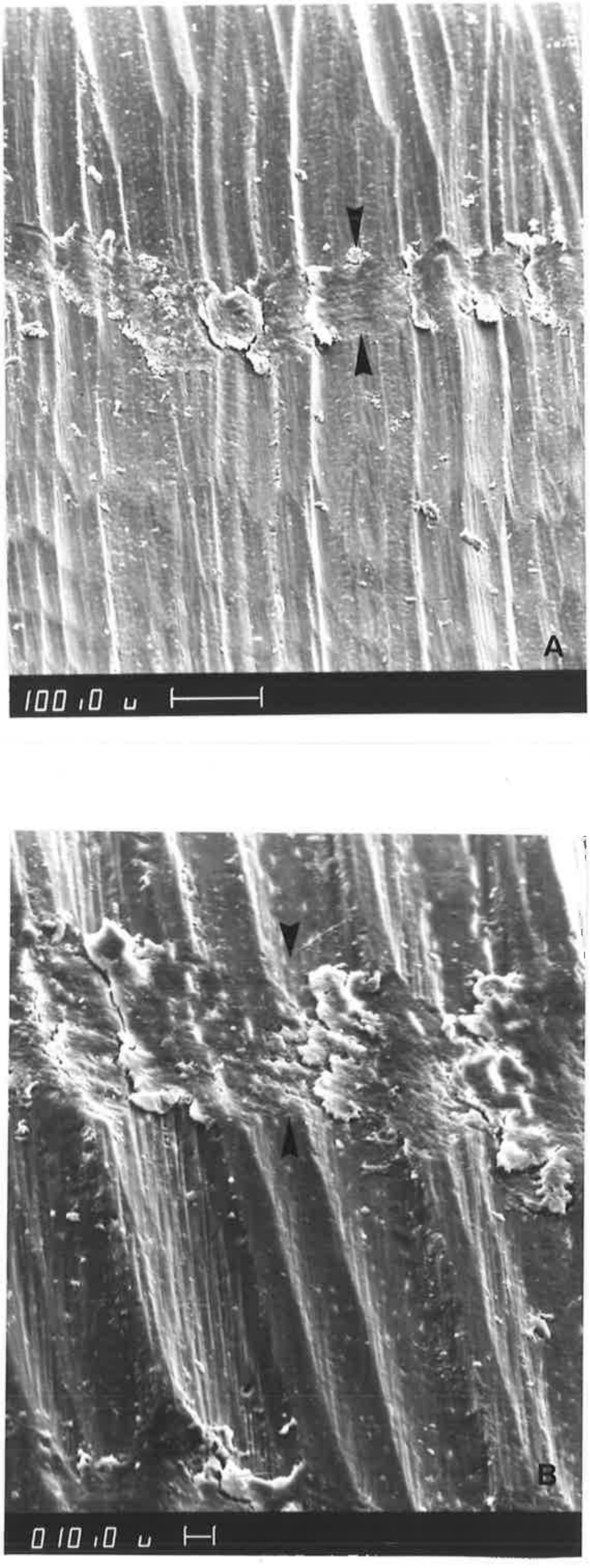


Fig. 5.4. A, B Photomicrographs of the effect of an American Dental Amflex I sickle explorer on a dentine surface prepared using a Fis L20 diamond bur. A x124, B x360.
Arrows delineate explorer tracks.

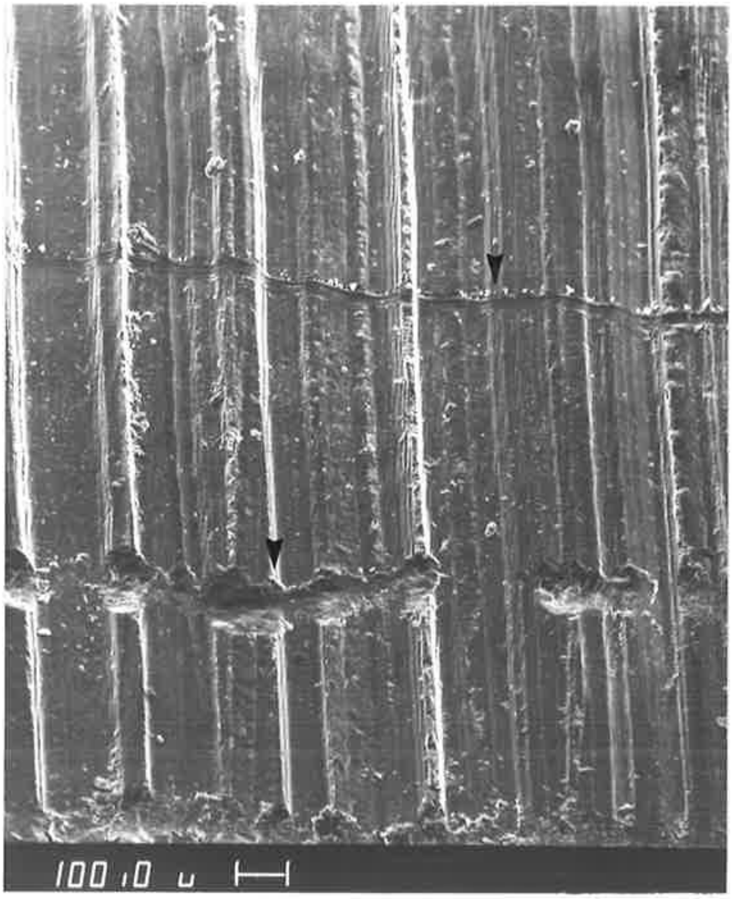


Fig. 5.5A
Photomicrograph of the effect of a profilometer stylus (top) and an American Dental Amflex I sickle explorer (bottom) on a dentine surface prepared using a Star 701 7P diamond. x54

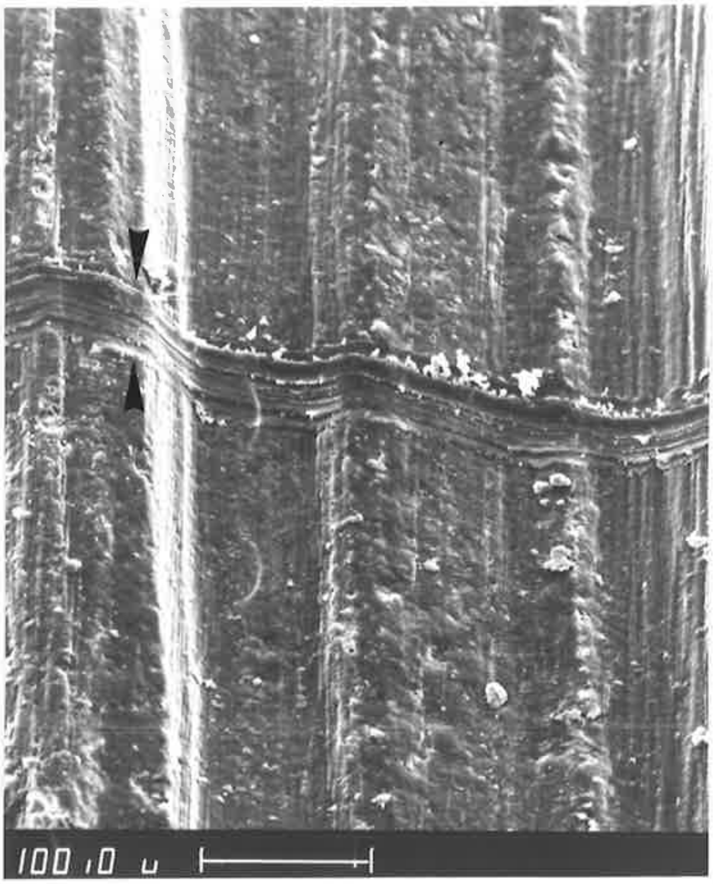


Fig. 5.5B.
Effect of a profilometer (arrows) x198.

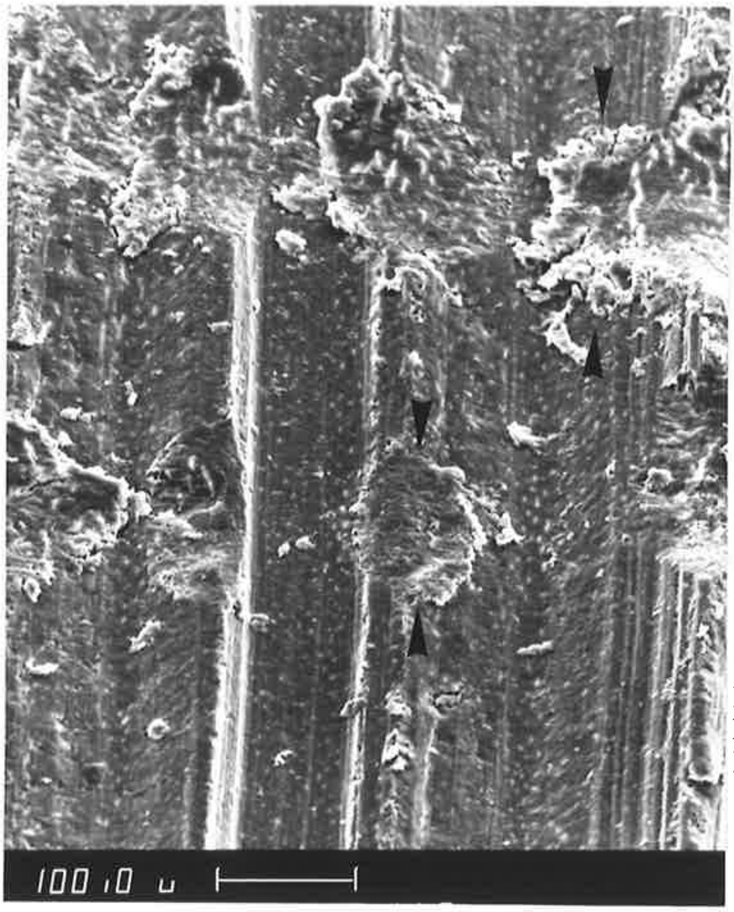


Fig. 5.5C.
Effect of an American Dental Amflex I sickle explorer (arrows) x162.

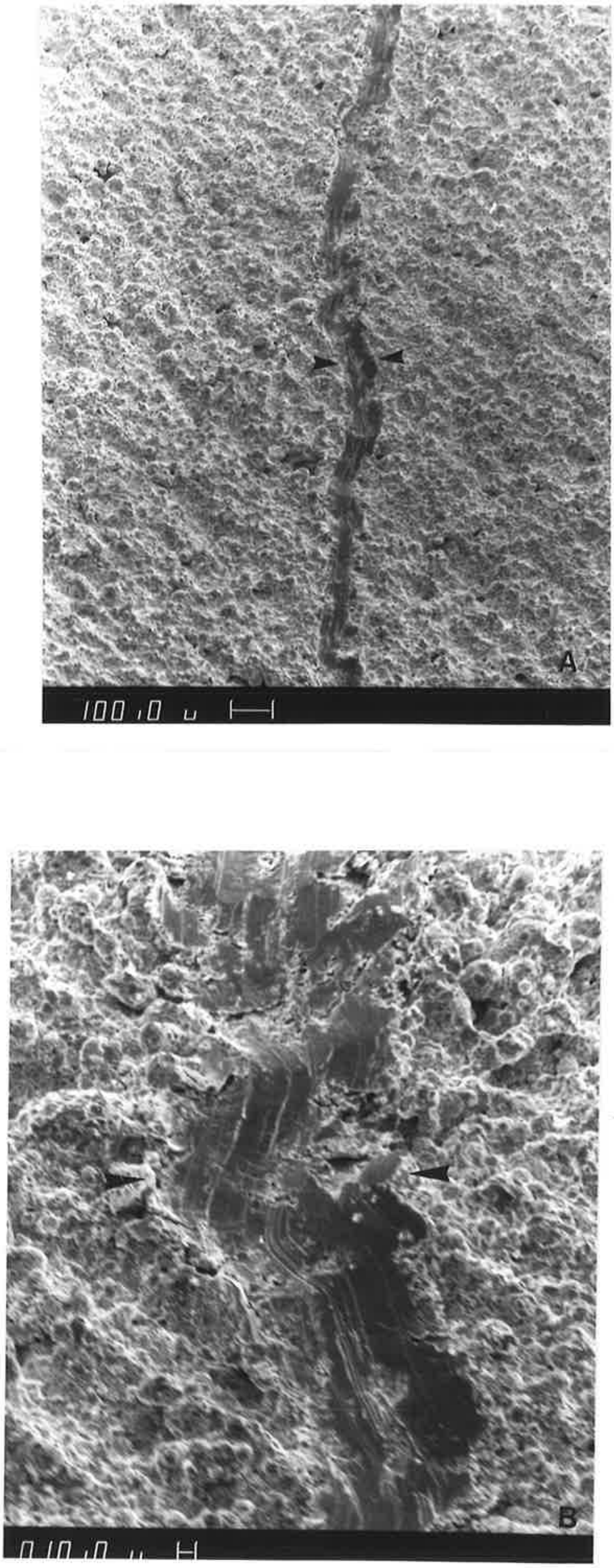


Fig. 5.6 A,B.
Photomicrographs of
the effect of an
American Dental Amflex
I sickle explorer on
unpolished Tytin
amalgam.
A x54
B x180

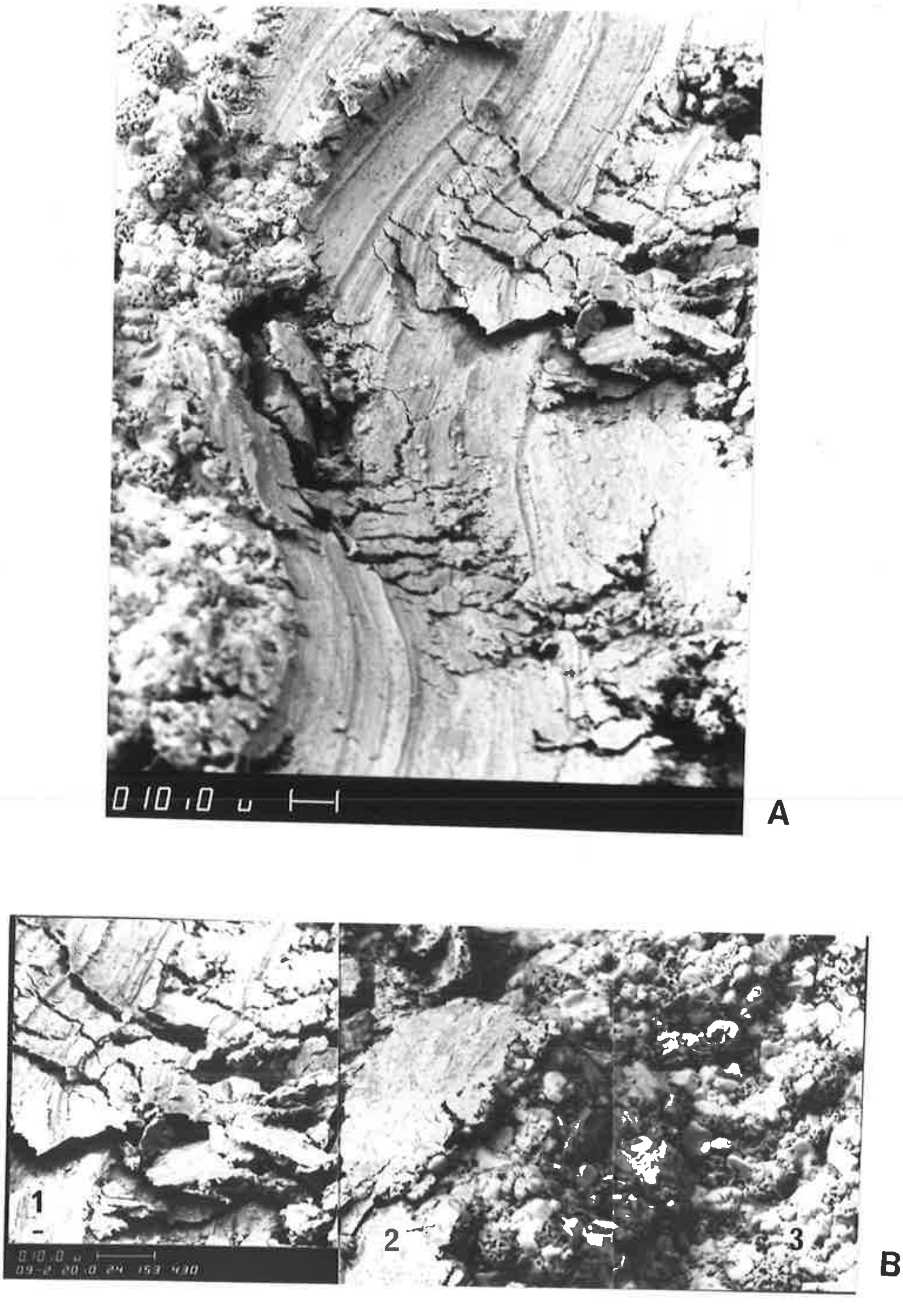


Fig. 5.7 A and B. Photomicrographs of the effect of an American Dental Amflex I sickle explorer on un-polished Tytin amalgam.
(A) x300.
(B) Montage x900.
1. surface at centre of groove made by explorer tine
2. rolled edge of groove made by explorer tine
3. amalgam surface before explorer was passed over it.

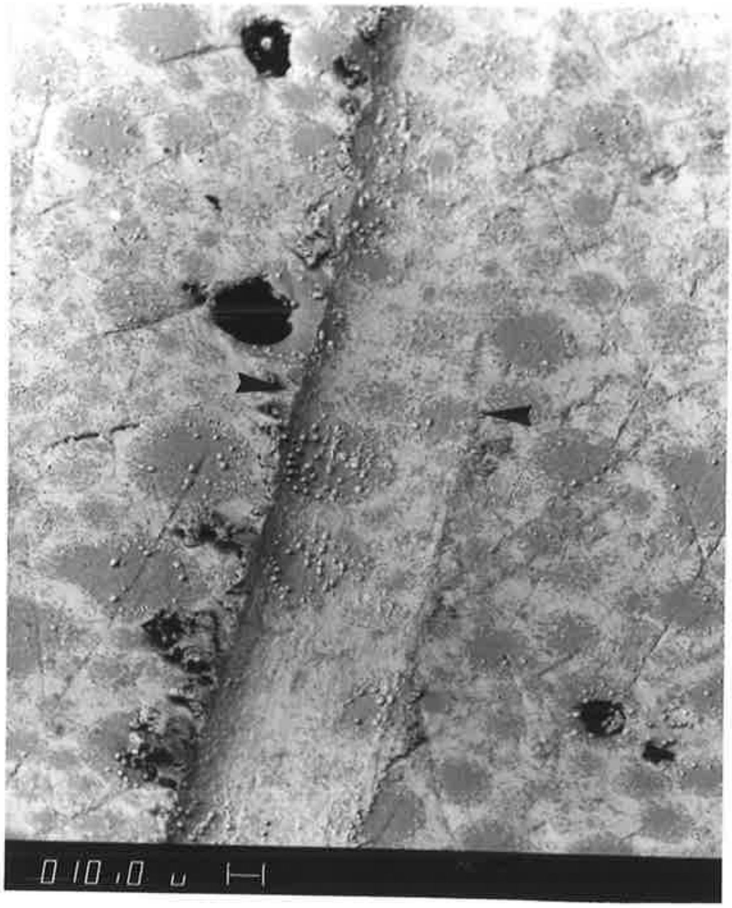


Fig. 5.8.
Photomicrograph of the effect of an American Dental Amflex I sickle explorer on Tytin amalgam polished to clinical standards x360. Arrows indicate track made by explorer tine.

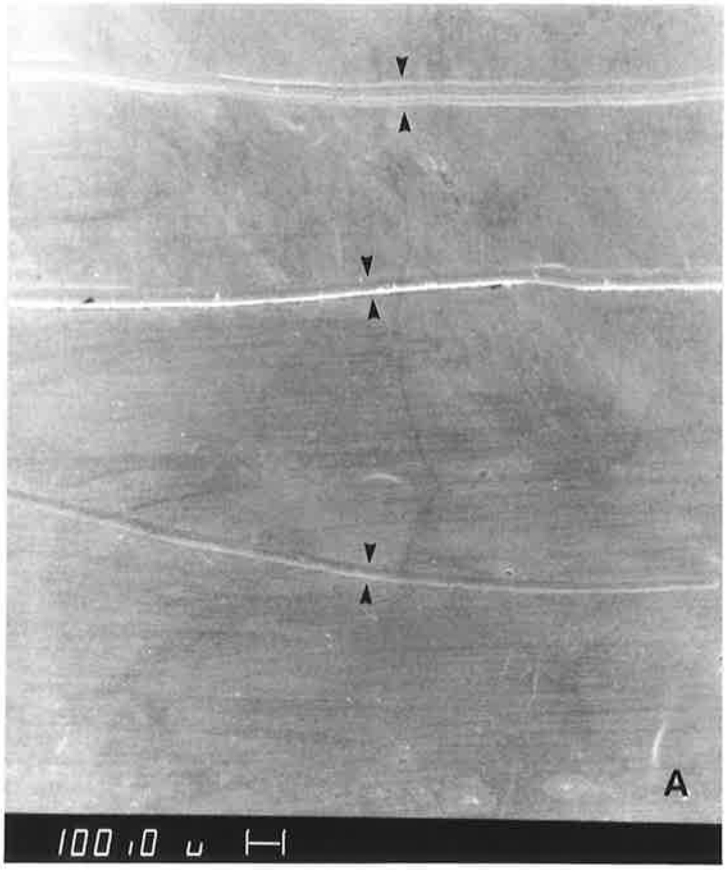


Fig. 5.9 A, B.
Photomicrographs of the effect of an American Dental Amflex I sickle explorer on a Ticon surface.
A x36
B x1440

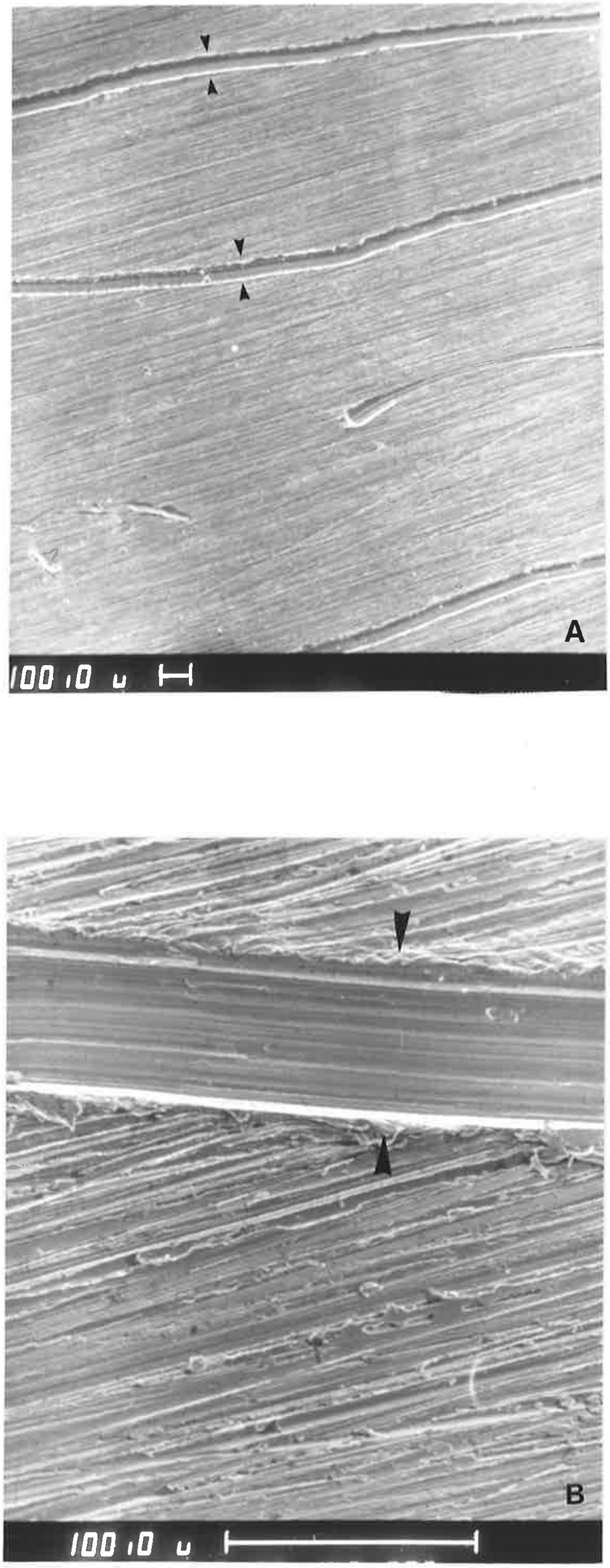
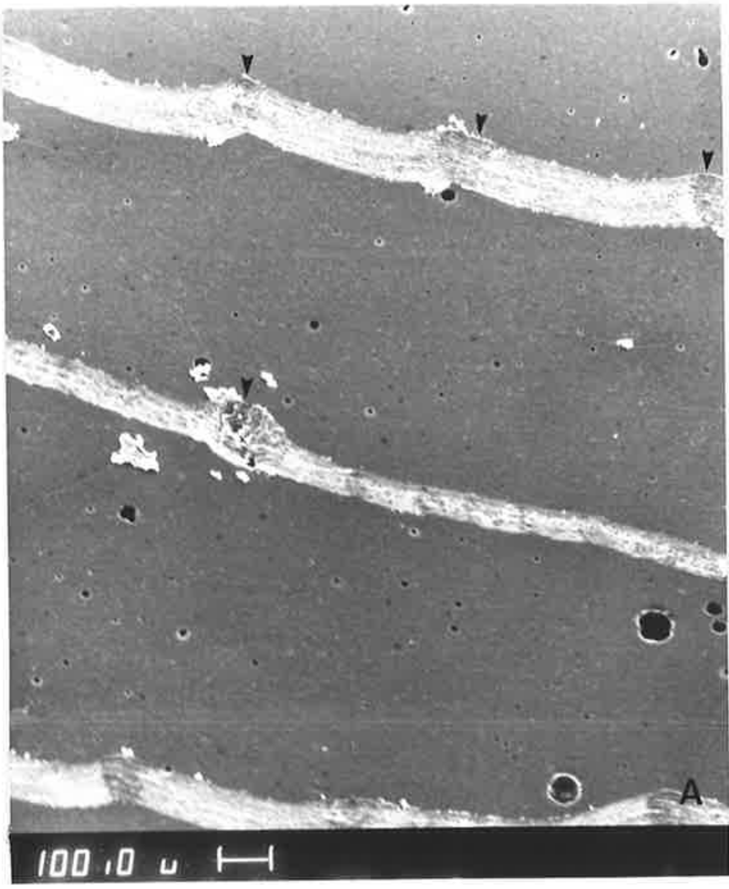


Fig. 5.10 A, B.
Photomicrographs of the effect of an American Dental Amflex I sickle explorer on a brass surface.
A x36
B x360



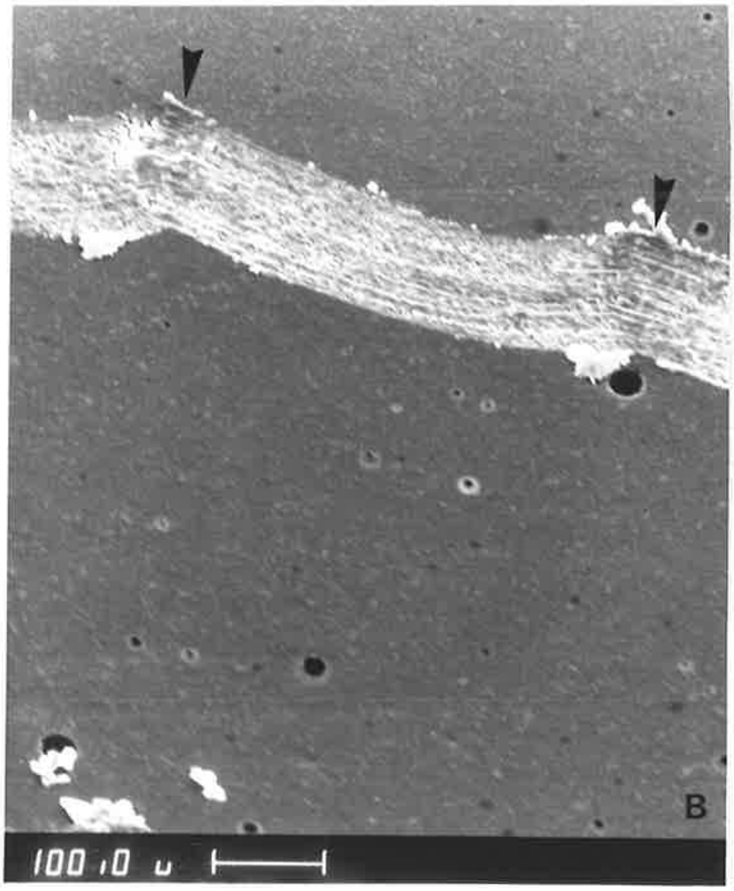
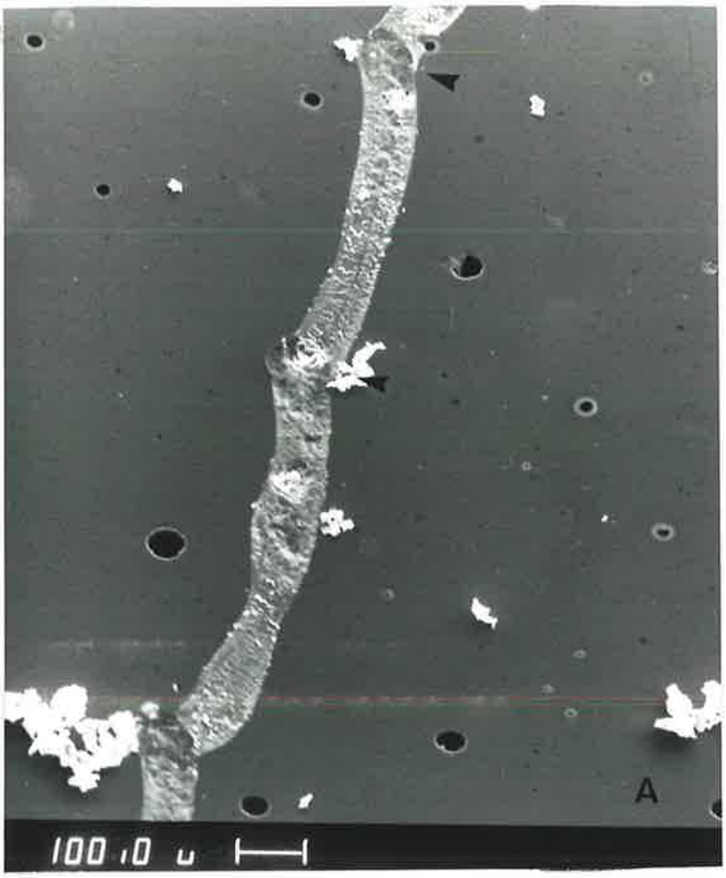


Fig. 5.11 A, B.
Photomicrographs of the effect of an American Dental Amflex I sickle explorer on the surface of Adaptic composite resin.
A x54
B x126



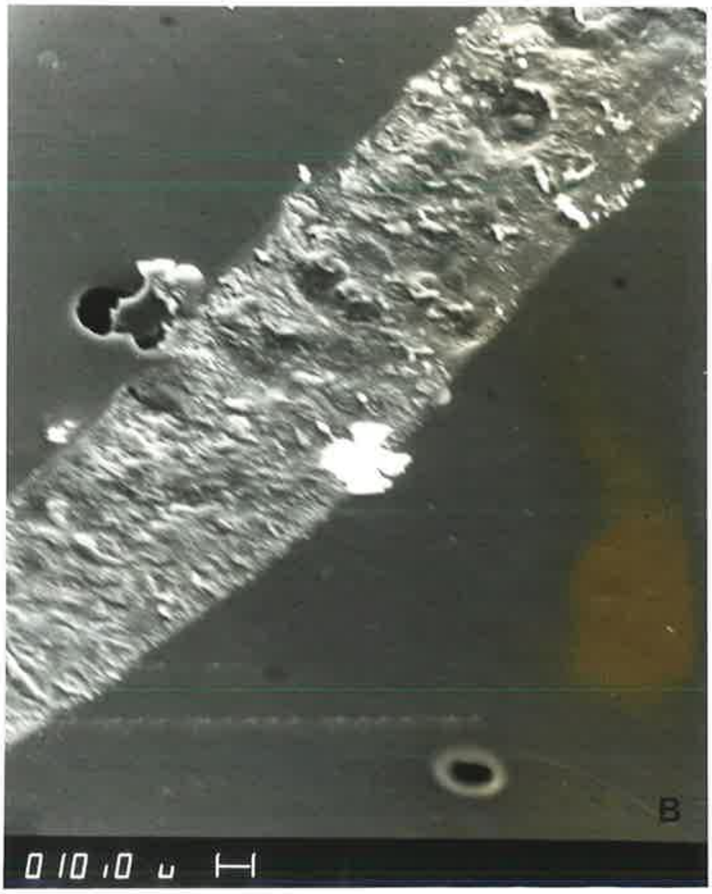


Fig. 5.12 A, B. Photomicrographs of the effect of an American Dental Amflex I sickle explorer on the surface of Heliosit microfilled resin.
A x72
B x360 (area of track between periodic markings).

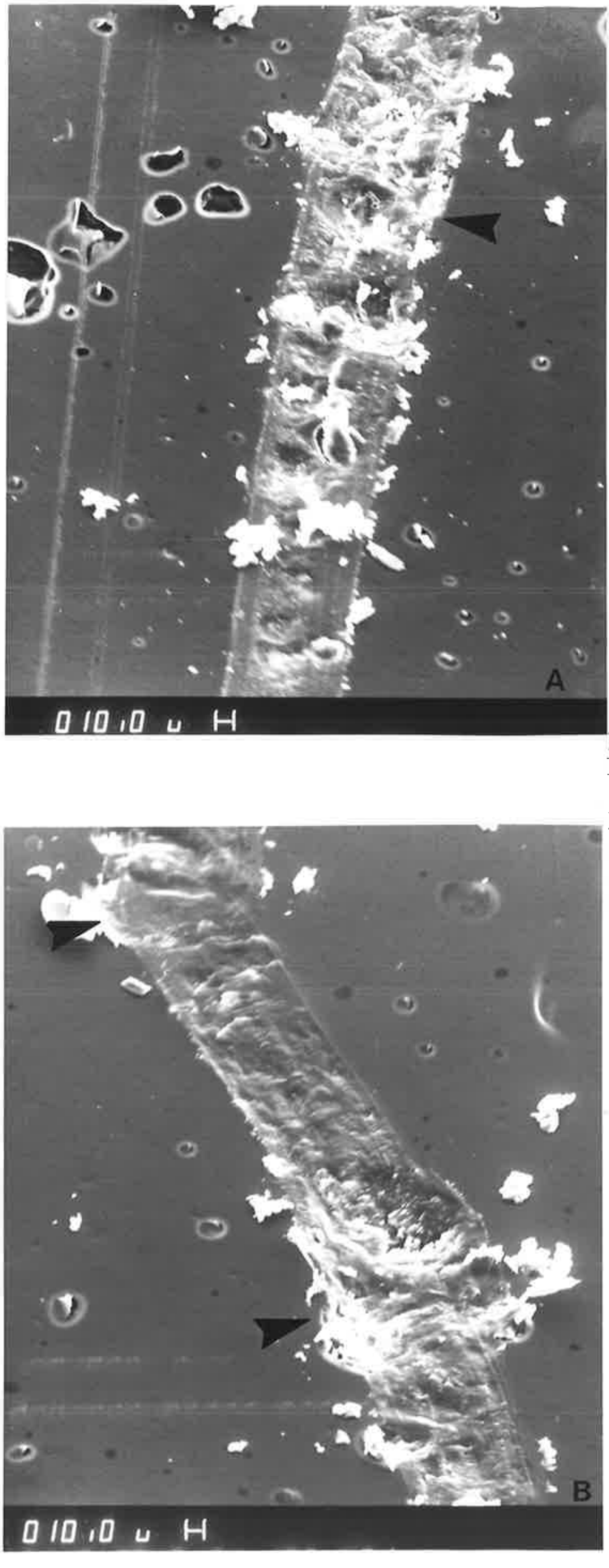


Fig. 5.13 A, B. Photomicrographs of the effect of an American Dental Amflex I sickle explorer on the surface of Durafil microfilled resin x180.

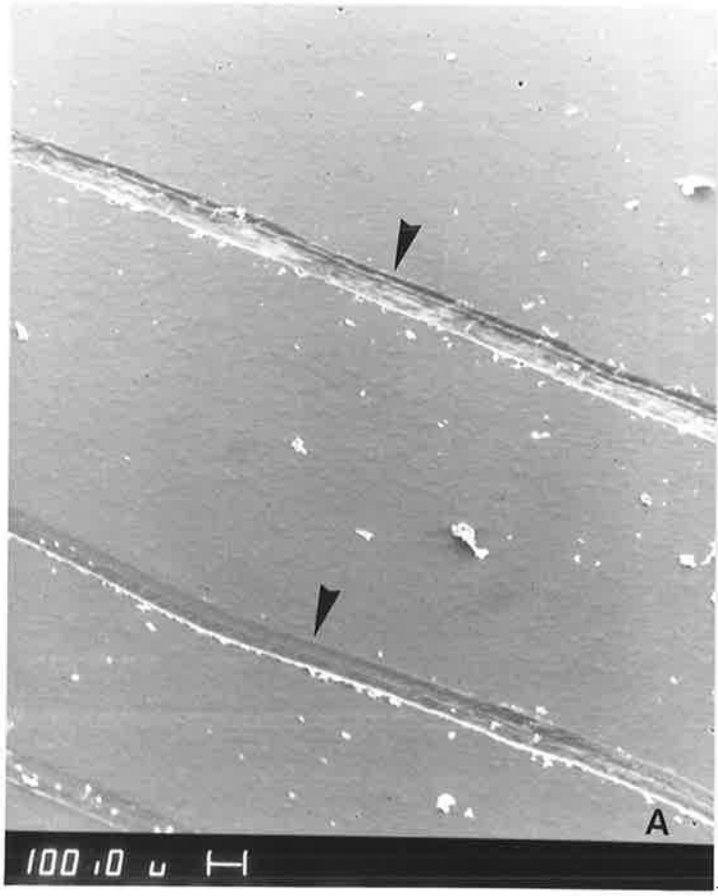


Fig. 5.14 A, B.
Photomicrographs of the effect of an American Dental Amflex I sickle explorer on the surface of Visiodispers micro-filled resin.
A x36
B x180

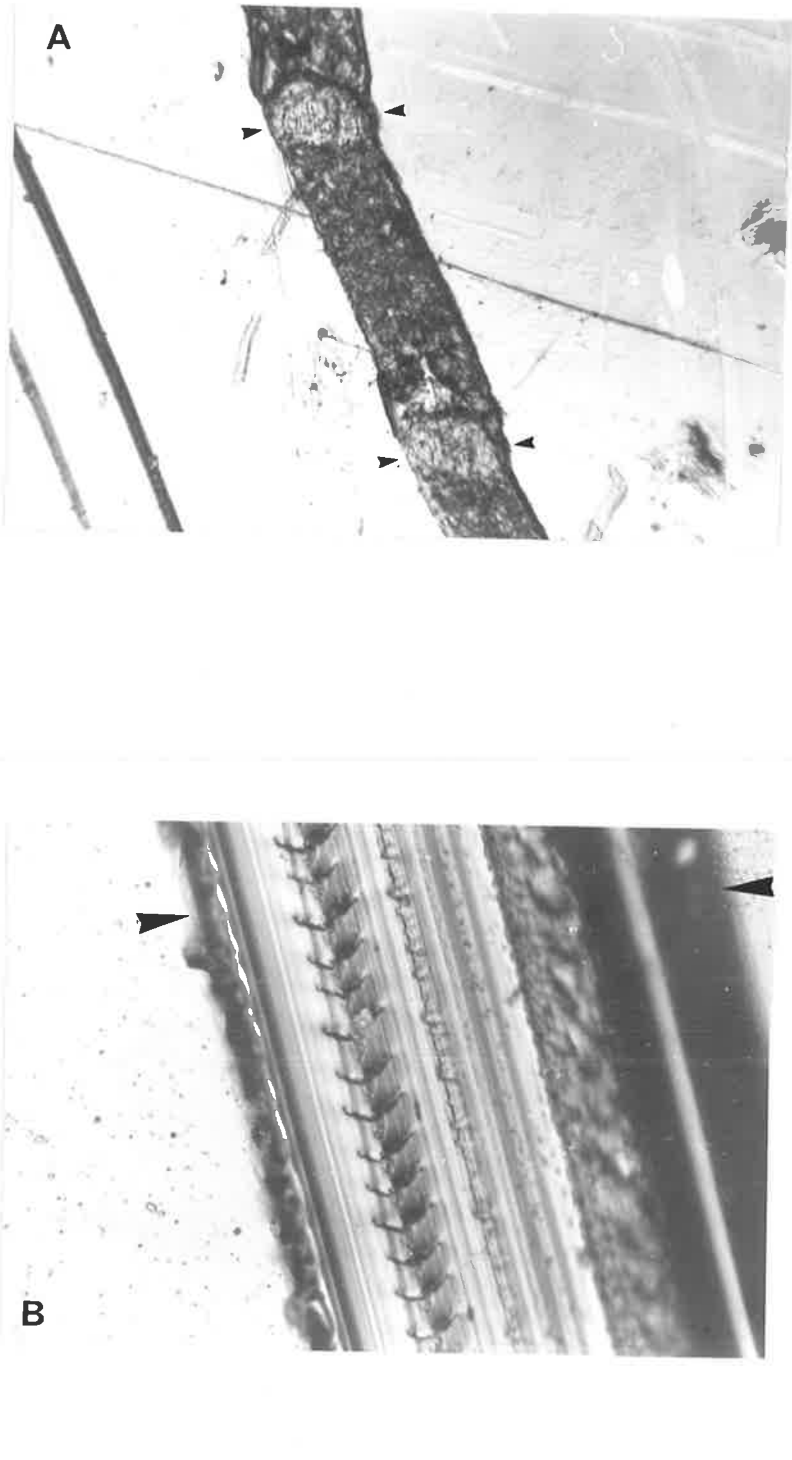


Fig. 5.15 A and B. Optical microscope views showing the effect of an American Dental Amflex I sickle explorer on a perspex surface. (A) x30. (B) x135.

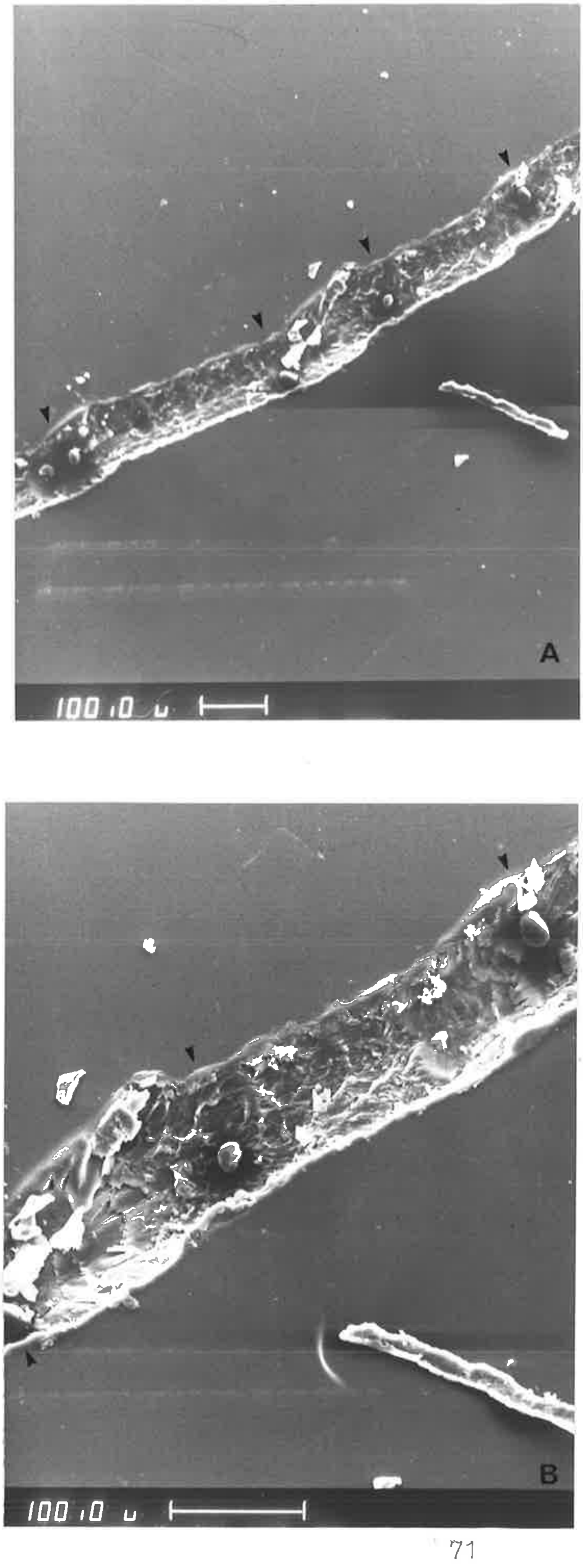


Fig. 5.16 A, B.
Photomicrographs of the effect of an American Dental Amflex I sickle explorer on a perspex surface.
A x90
B x198

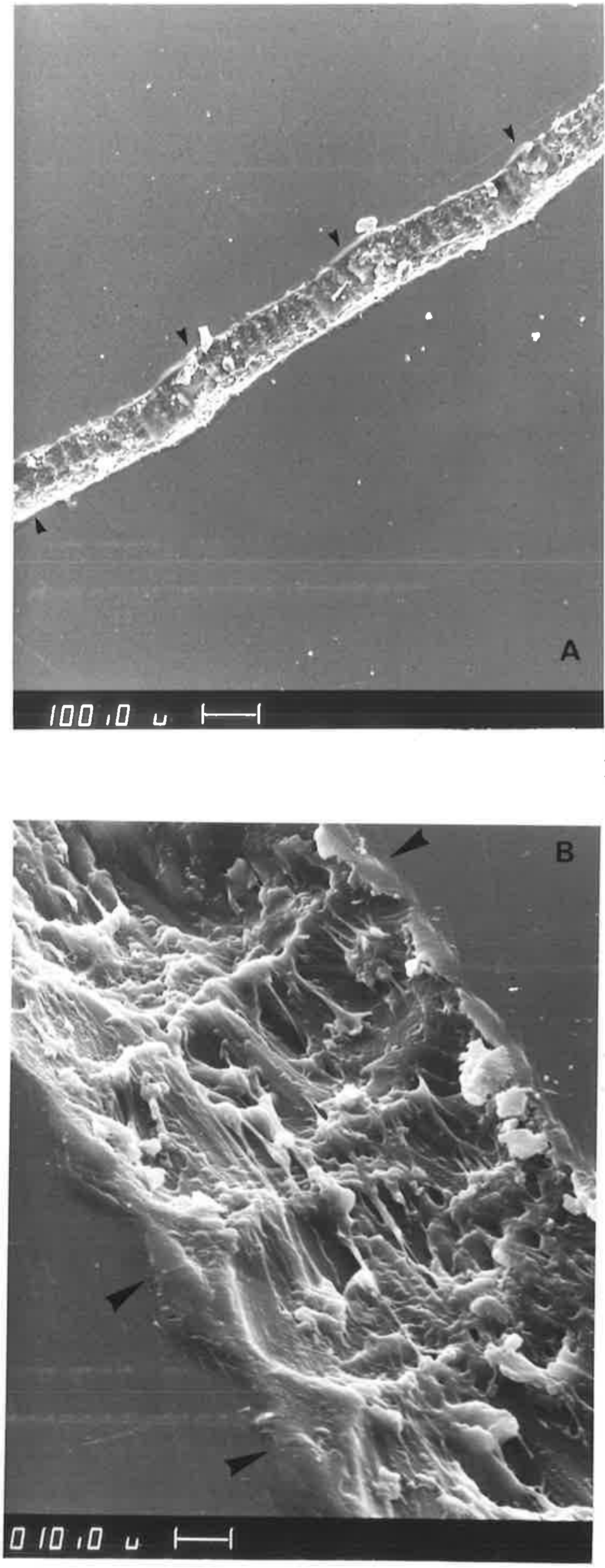
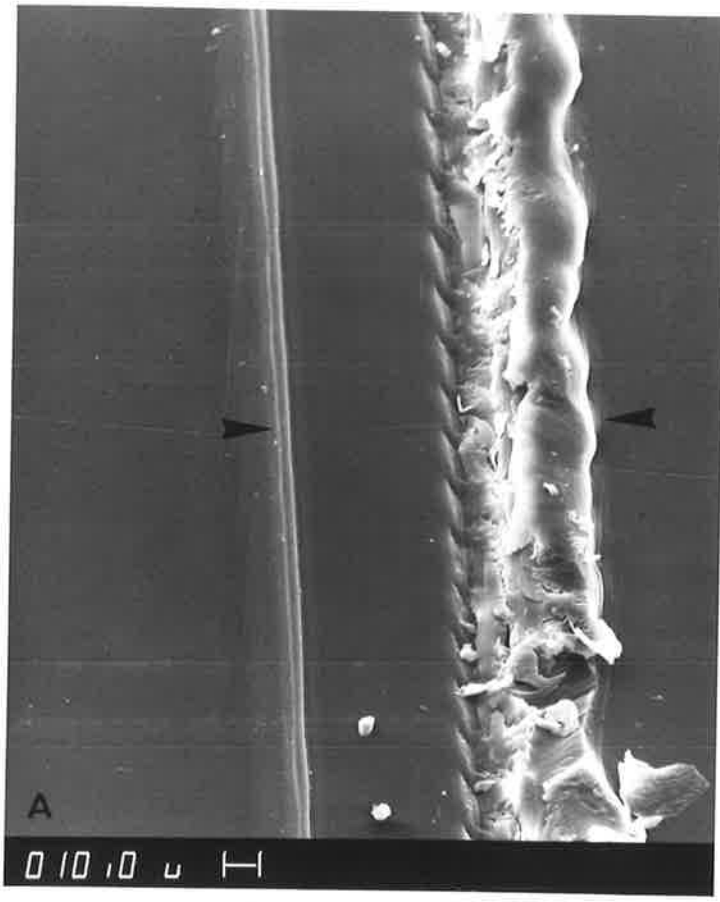


Fig. 5.17 A, B.
Photomicrographs of the effect of an American Dental Amflex I sickle explorer on a perspex surface.
A x72
B x720



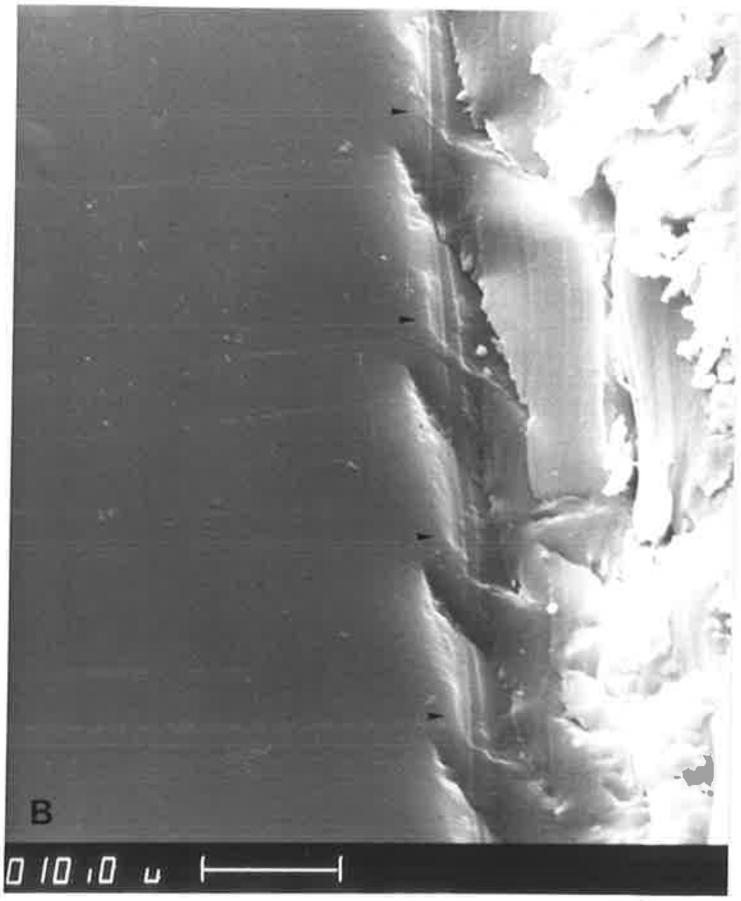


Fig. 5.18 A, B.
Photomicrographs showing part of the effect of an American Dental Amflex I sickle explorer on a perspex surface.
A x360
B x1620

5.1.2 RESULTS AND DISCUSSION

Figs. 5.1 to 5.18 are representative of the effects of the explorer and profilometer stylus affecting the prepared surfaces.

On the enamel surface, the dental explorer produced a smooth, shallow groove. On the basis of the hardness of enamel a deep groove would not be expected. No periodicity was detected in the explorer tract and surface irregularities did not appear to influence the tine groove (Fig. 5.1).

The metal surfaces of Ticon and brass also demonstrated grooving which had no definable pattern; Ticon being a harder material than brass, accordingly had shallower grooves. As for enamel, surface irregularities did not appear to influence the tine groove. However due to the greater ductility of these materials as compared to enamel, the metal surfaces had increased smearing and a rolled edge of metal was apparent at the outer borders of the explorer tract (Figs. 5.9 and 5.10).

When attempting to evaluate the character of a dentine surface by tactile means with a dental explorer, then ideally the explorer tine should accurately trace the surface topography. On dentine surfaces prepared using diamond rotary instruments it was observed that the explorer tine failed to negotiate all the existing peaks and troughs (Figs. 5.4, 5.5A,C), with the explorer tending to skip across the surface indicating a periodicity of contact. In addition to this the explorer tine demonstrated a tendency to cut into the peaks which were contacted (Fig. 5.4, 5.5A,C) and the dentine dislodged at these points was smeared into the adjoining trough regions (Fig. 5.4B). Therefore in effect, using a dental explorer as a medium to perceive the roughness of a prepared tooth surface results in alteration of topographical features at the point of examination which must result in inaccuracy of the transmitted information pertaining to the surface being examined. This was more obvious on surfaces with a finer texture (Fig. 5.4). Periodic markings on a surface would indicate that the tine traversed that surface in a vibrative mode. Such a periodic pattern was evident on the dentine surface prepared using a carborundum disc (Fig. 5.2); however, this pattern appeared to be independent of the surface roughness of the preparation and may be instrument related.

In comparing the effects of a profilometer stylus with those of the dental explorer, the profilometer tip appeared to traverse the prepared dentine surfaces more accurately (Figs. 5.3, 5.5A,B) and the change to the surface texture was minimal.

When an American Dental Amflex I sickle explorer was used on an unpolished Tytin amalgam surface an irregular track was imparted to the amalgam surface (Fig. 5.6). There were no periodic markings evident, but backscattered electron views revealed smearing and layering of the surface amalgam with resultant formation of surface microcracks (Fig. 5.7). A rolled edge of displaced material at the border of the explorer tine track was also a notable feature. Of clinical significance, the microcracks and rolled edges contain voids which represent areas possible for initiation of corrosion.

Using a dental explorer over polished Tytin amalgam produced a different effect to the unpolished amalgam surface (Fig. 5.8). On the polished surface, the resultant grooving appeared smooth and no microcracks were visible. However, as with the unpolished surface no periodic markings were evident and smearing of the surface produced a rolled edge of displaced material at the borders of the track.

The other types of restorative materials investigated in this study were the resin materials. Markings produced on the conventional composite resin material (Adaptic) by a dental explorer demonstrated periodic characteristics (Fig. 5.11). This vibratory pattern was not related to the surface profile or to filler particle size. Aside from the periodicity, the resin surface was distinctly roughened by the explorer as compared to the surrounding untouched surface, with resin material being torn and removed by the explorer tine leaving a granular surface (Fig. 5.11B).

Of the microfilled resin materials tested, both Durafil and Heliosit revealed the generation of a periodic pattern by the explorer tine (Figs. 5.12, 5.13) but this was more evident for the Heliosit. However, the third microfilled resin used in this study (Visiodispers) revealed no distinctive evidence of periodicity (Fig. 5.14). This feature could be due to differences in the physical nature of Visiodispers compared to Durafil and Heliosit or it may have been due to the way in which the explorer was held.

The observation of the effects of a dental explorer on the perspex surfaces revealed a number of noteworthy points. Firstly the optical microscope views demonstrated two types of explorer tracks with periodic markings (Fig. 5.15). The S.E.M. photomicrographs of the effects of a dental explorer on perspex surfaces revealed additional patterns of periodic markings (Figs. 5.16, 5.17, 5.18). Fig. 5.17 illustrates tine vibration with two frequency patterns. The most noticeable effect on perspex surfaces was that of melting to either form globules (Fig. 5.16) or raised ridges (Fig. 5.17B). Fig. 5.18B indicates that in addition to melting, minute stress cracks may occur on the surface in areas of stress concentration.

A theoretical explanation for the effects seen in Fig. 5.18 is that in drawing an explorer tip across the perspex surface, there was melting and tearing of the surface on one side of the track (right side of Fig. 5.18A), plastic deformation of the surface on the opposite side of the track (left side of fig. 5.18A), whilst the centre portion was elastically deformed (Fig. 5.19).

IN SUMMARY

When using a dental explorer as a medium to assess surface roughness, then ideally the explorer should transmit the relevant information without causing a change in the surface being examined. In this study this was not observed and it was evident that:

1. The explorer tip cut into dental hard tissues and restorative materials with a degree of surface tearing, smearing and melting being apparent.
2. The explorer tip may skip across a surface indicating a periodicity of contact.
3. Originally smooth surfaces can be roughened by explorer examination.
4. Periodicity markings appear to be independent of the surface roughness.

Further study is necessary to determine the amount and sequence of explorer tine deflection during its use for the purpose of surface roughness evaluation. A possible method for this would be the use of strobe lighting combined perhaps with time lapse photography.

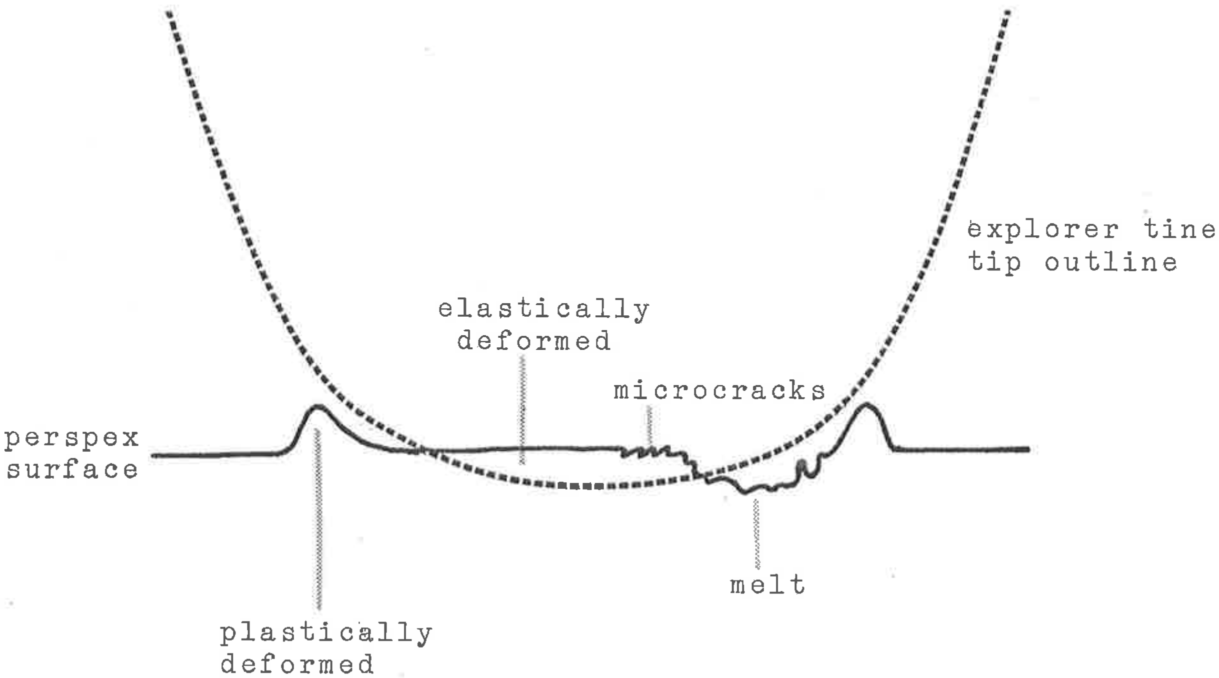


Fig. 5.19. Diagrammatic representation of the effects on perspex of a sickle explorer when drawn across the surface as for surface roughness evaluation (as in Fig. 5.18).

5.2 TIP WEAR

Tine tip wear is dependant on the hardness of the tine material and according to Guthrie (1981), the optimum hardness value for any explorer tine tip should be above 70 Rockwell C. The problem encountered with increasing hardness value is the accompanying increase in brittleness. Taking this into consideration, the American Dental Manufacturing Company has accepted a Rockwell hardness value range between 51 to 56 for their explorer tines.

Tip wear for Ivoclar dental explorers has been summarised as follows:

> "The K type explorer which you purchase is ......, made out of austenitic stainless. This steel is sufficiently hard to maintain its shape during normal use, but is of course, not as hard as the heat-treated type of point which we also produce. When the austenitic point is pulled across a rough surface, there is wear, and if excessive loads are applied, the extreme point (last 1/2 mm) will bend, whereas on the heat-treated point, the end will wear, and if excessively loaded, the point can break off. The user, therefore, has to make a choice". (DONOVAN, 1981).

5.2.1 MATERIALS AND METHODS

Enamel and dentine surfaces were prepared using a Star No. 701 7P tapered fissure diamond bur in an air turbine handpiece, hand held, with water spray, at approximately 300,000 r.p.m. A "new" sickle explorer (American Dental Amflex I No. 2*) was passed over 5 mm lengths of these surfaces as for detecting surface roughness. The direction of movement of the explorer over the test surface was across the grain of cut.

The tine tip was photographed under an optical microscope before commencement (new), following twenty single strokes across the enamel and dentine surfaces and then after fifty strokes. For comparison an American Dental Amflex I No. 5 sickle explorer tine selected at random from the hospital clinic was also photographed.

Another comparison was made between an American Dental Amflex I No. 5 sickle explorer tine selected at random from the hospital clinic and a sewing needle using the scanning electron microscope.

* American Dental Manufacturing Co., Missoula, Montana, U.S.A.

5.2.2 RESULTS AND DISCUSSION

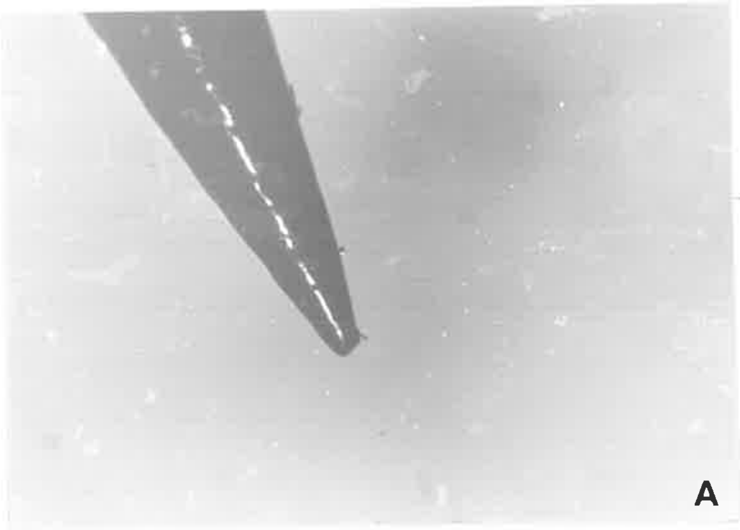
Figs. 5.20 to 5.24 are representative of explorer tine tips.

Figs. 5.21 and 5.22 indicate that a comparatively minimal amount of wear of the tine tip occurs when the explorer is used for the assessment of surface roughness. In contrast to this, studies undertaken by Miller (1951) and Iwakura and Shimada (1978) revealed that considerable wear of tine tips was evident when explorers were used for detection of pit and fissure caries.

However, no direct comparison can be made between this study and those of these authors since different explorers were used for each of the three studies, and there is the difference in the method of use of an explorer when it is used for assessment of surface roughness as compared to the detection of pit and fissure caries.

The necessity for the explorer tine point to be sharp has been extensively discussed in the literature by Jackson (1950), Miller (1951), Crocker (1975), and Iwakura and Shimada (1978). In contrast to this study, all of the above studies have concentrated on the use of an explorer as an instrument for the detection of caries where the explorer is required to penetrate into the tooth. The results obtained in the previous section of this study (Section 5.1) cast doubt on the value of an

Fig. 5.20. Photomicrograph of an American Dental Amflex I No. 5 sickle explorer tine selected at random from a hospital clinic. x75



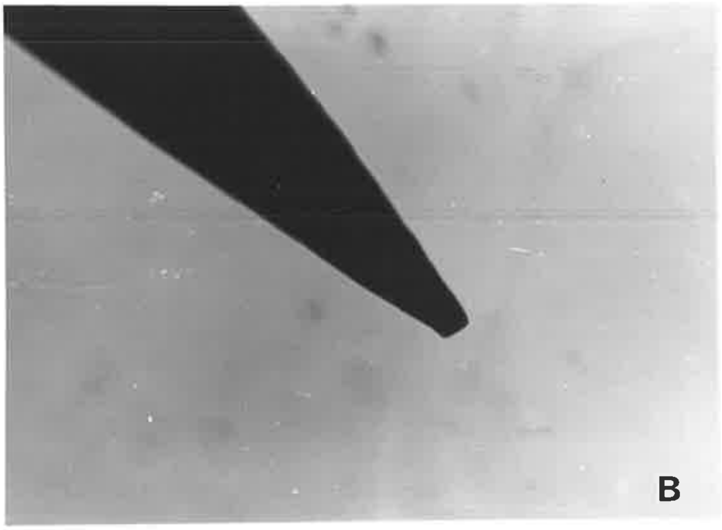
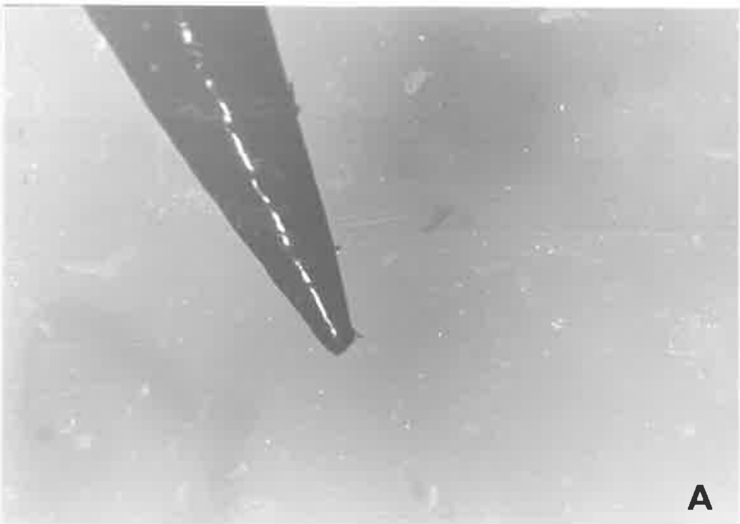


Fig. 5.21 A, B and C. Photomicrographs of an American Dental Amflex I No. 2 explorer tine tip.
(A) new x30.
(B) following 20 single strokes over an abraded dentine surface x30.
(C) following 50 single strokes over an abraded dentine surface x30.



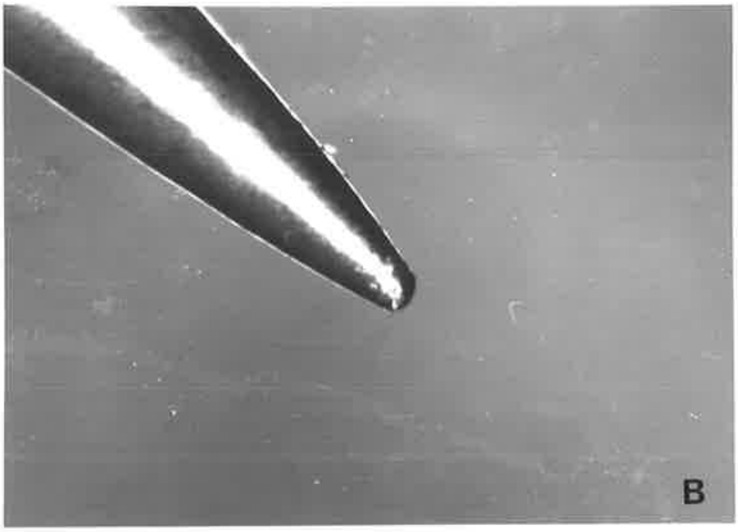


Fig. 5.22 A, B, and C. Photomicrographs of an American Dental Amflex I No. 2 explorer tine tip.
(A) new x30.
(B) following 20 single strokes over an abraded enamel surface x30.
(C) following 50 single strokes over an abraded enamel surface x30.

extremely sharp point for the detection of surface roughness because of the failure to accurately track the surface profile. This point raises the question of a possible disastrous effect to remineralization if an early demineralized lesion is disturbed and cavitated (KOULOURIDES, 1981; OSTROM, 1981), and should encourage further thought regarding the indication for a sharp explorer tine. Furthermore it has been shown that in relation to the detection of carious lesions, electronic devices which measure the electrical resistance in enamel are more sensitive and less subjective instruments as compared to explorers (WILLIAMS et al, 1978; WHITE et al, 1981).

Comparing an American Dental sickle tine with a sewing needle, (Fig. 5.23) the sewing needle showed a smoother surface finish with a finer and more regular degree of taper. The quality of the surface finish may be attributed to differences in the material of manufacture. Furthermore sewing needles are tumble sharpened rather than hand sharpened, and the result is a more uniform taper on the needle. Recently Sato and Shimura (1981) discussed the efficacy of sewing needles for the diagnosis of dental caries.

The presence of the micro-irregularities evident on the explorer tine (Fig. 5.24) is of additional interest in this study as it is known that explorer tines are effective instruments for the transmission of cariogenic bacteria between teeth (SVANBERG, 1978).

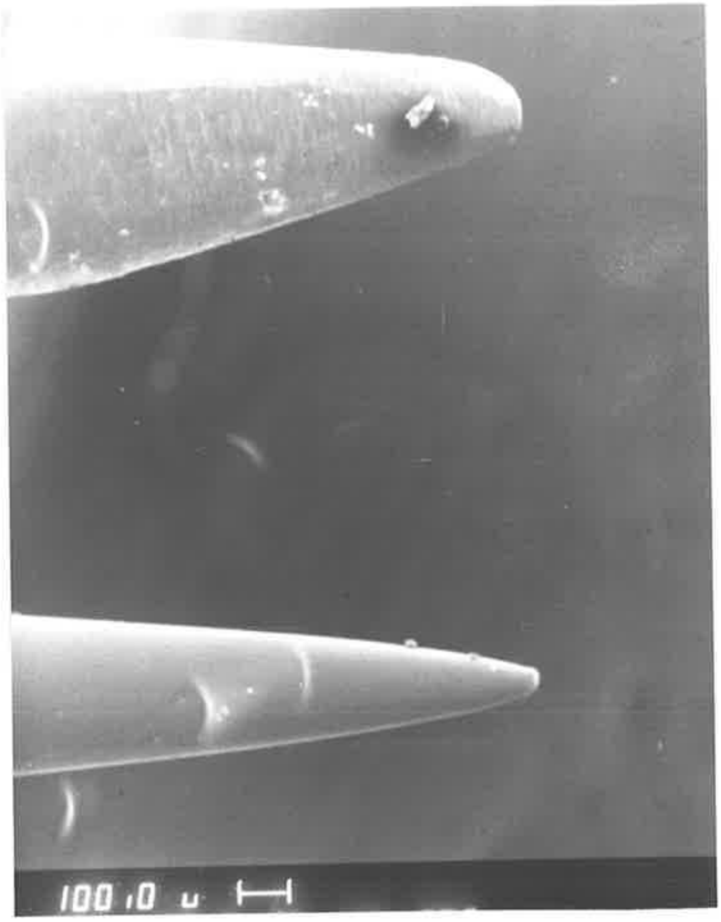


Fig. 5.23.
Photomicrograph of an American Dental Amflex I sickle explorer tine tip (top) and a sewing needle (bottom). x54

Fig. 5.24.
Photomicrograph of tine tip of an American Dental Amflex I sickle explorer selected at random from the clinic. x720

IN SUMMARY

1. Explorer tine tips manufactured by the American Dental Manufacturing Company demonstrate a comparatively minimal amount of wear when used across enamel and dentine surfaces as for the detection of surface roughness.
2. Comparing an American Dental sickle tine with a sewing needle, the sewing needle showed a smoother surface finish with a finer and more regular degree of taper.
3. In light of the micro-surface characteristics of the American Dental Amflex I sickle explorer tine tip, the relationship between this and the mechanism of bacteria transmission warrants further study.

5.3 **TINE RIGIDITY**

This study was carried out to examine the explorer tine rigidity. The British Standard test was compared with three other test methods.

5.3.1 <u>TO EXAMINE THE BRITISH STANDARD TEST OF MECHANICAL PROPERTIES OF PROBES TO CHARACTERISE TINE RIGIDITY</u>

The British Standard 2965:1970 (Australian Standard 1086:1971) includes a bending test to classify explorers as being either (1) flexible or (2) rigid.

5.3.1.1 <u>Materials and Methods</u>

According to appendix B3 and B5 of BS 2965:1970; the test requires that the tine of the probe is held firmly at a distance of 2 mm from the tip in a clamp with the handle of the probe pointing vertically upwards. While in this position a force of 0.098N is applied to the axis of the handle in such a direction that the least possible torsion is applied to the tine. Whilst the force is still applied a measurement is taken of the deflection at right angles to the original line of the handle at a point on the handle 125 mm from the point of entry of the tine into the clamp (Fig. 5.25). In order to compare relative rigidity between explorer tines the following seven explorers were selected and tested:

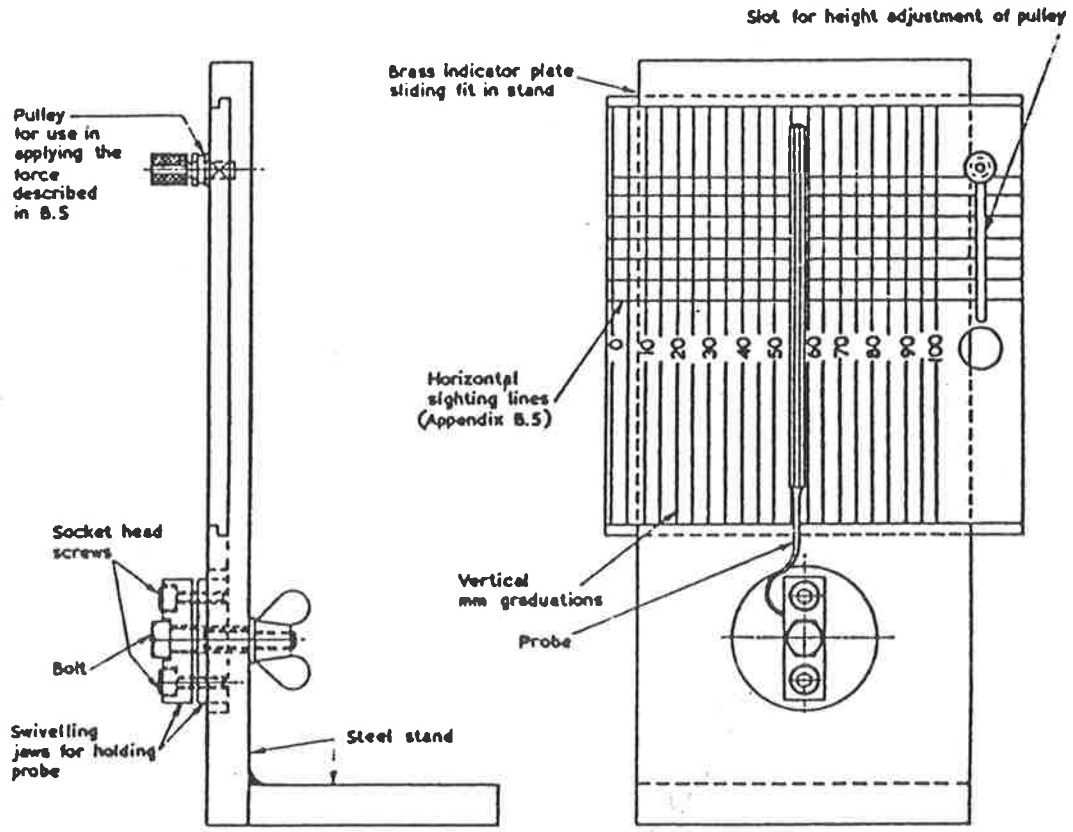


Fig. 5.25. **Apparatus for testing the mechanical properties of probes**
(British Standard 2965:1970)
(Australian Standard 1086:1971)

Neos No. 23*; American Dental Amflex I No. 5** sickle end; Ash England No. 2***; Ash England Pro 54***; Starlite No. 5+ sickle end; Starlite No. 17S+ straight hooked end; Todent No. 2++ (Fig. 5.26).

5.3.2 TO EXAMINE A MODIFIED BRITISH STANDARD TEST OF MECHANICAL PROPERTIES OF PROBES TO CHARACTERISE TINE RIGIDITY

5.3.2.1 Materials and Methods

The British standard test procedure outlined in section 5.3.1 was altered so that the force of 0.098N applied to the axis of the handle was in a direction at 90^{o} to the form of the explorer (that is, a lateral load) (Fig. 5.27).

The same seven explorers as for section 5.3.1 and 5.3.2 were tested (Fig. 5.26).

5.3.3 TO EXAMINE THE USE OF A WIRE BEND TESTING MACHINE (TINIUS OLSEN COMPANY) TO CHARACTERISE RIGIDITY - DEFLECTION OF EXPLORER TIPS

* Neos Dental Co., Switzerland
** American Dental Mfg Co., Missoula, Montana, USA
*** Ash Division, A.D. International Co., London
\+ Star Dental, A Syntex Dental Co., USA
\++ Todent Co., Japan

5.3.3.1 Materials and Methods

A Tinius Olsen stiffness tester (6 inch-pound capacity)* was used to test the stiffness of the explorer tines. The handle of the explorer was rigidly clamped in the machine, whilst the bending force was applied to the tine of the explorer at a point 2 mm from the tine tip, and in a direction 90° to the form of the explorer (Fig. 5.28).

The same seven explorers as for section 5.3.1 and 5.3.2 were tested (Fig. 5.26).

5.3.4 TO EXAMINE A DEAD WEIGHT TESTER WITH LIGHT LOADS FOR DEFLECTION OF EXPLORER TINES

5.3.4.1 Materials and Methods

The explorer handle was rigidly clamped to a metal stand which allowed the tine to project outwards from the base of the support. Simulating clinical use, three separate weights of 10 grams, 20 grams and 50 grams were each in turn, individually suspended from the explorer tine at a point 2 mm from the tine tip, in a direction at 90° to the form of the explorer. Tine deflection was measured with a Vernier microscope eyepiece. Three measurements were taken for each weight applied and an average reading calculated for the deflection (Fig. 5.29).

* Tinius Olsen Testing Machine Co., Pennsylvania

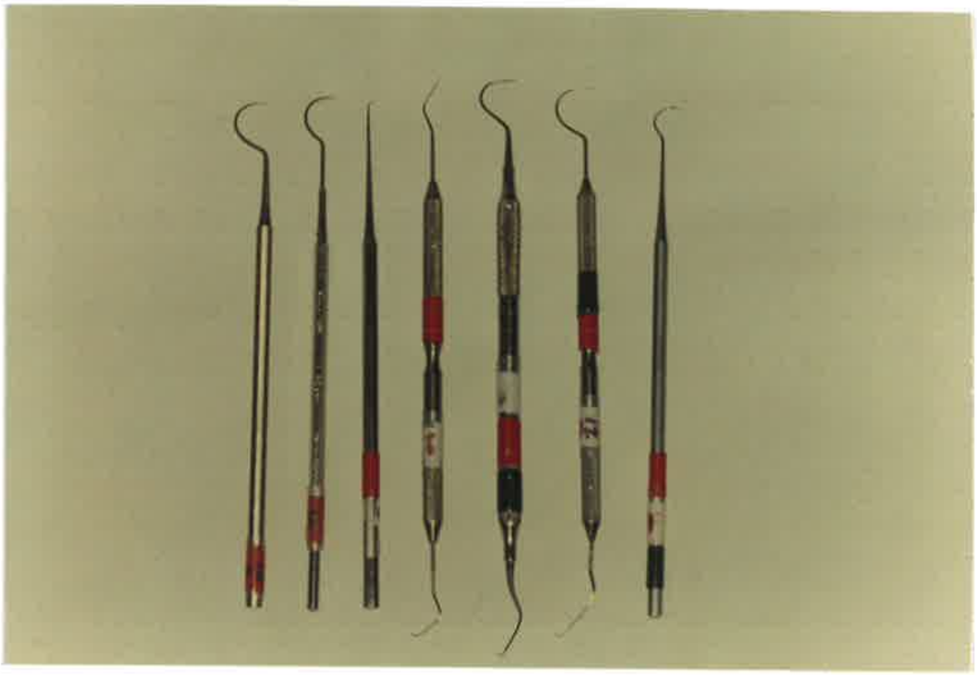


Fig. 5.26. Explorers: (from left) Ash England Pro 54, Neos No. 23, Todent No. 2, Starlite No. 17S, American Dental Amflex I No. 5, Starlite No. 5, Ash England No. 2.

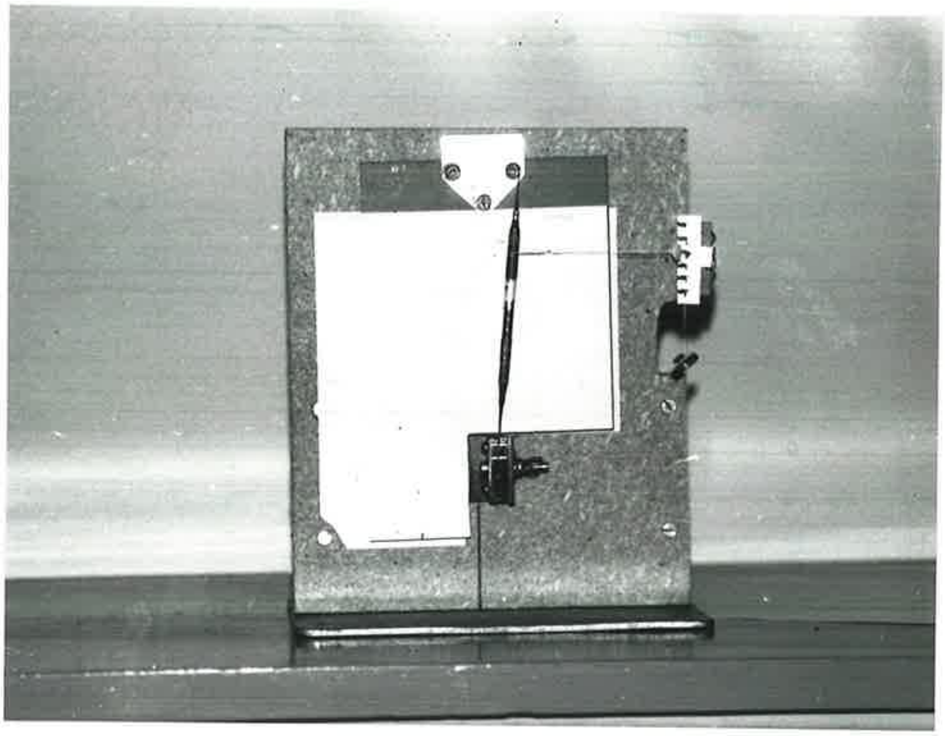


Fig. 5.27. Modified British Standards test apparatus so that the force is applied to the axis of the handle in a direction 90° to the form of the explorer.

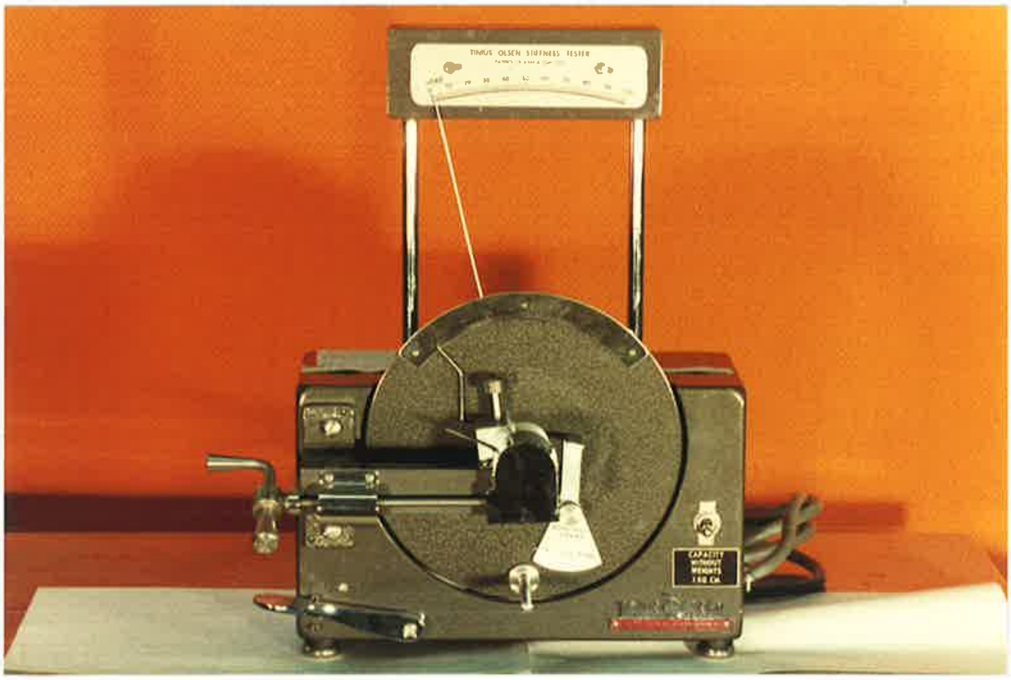


Fig. 5.28.
Tinius Olsen stiffness tester.

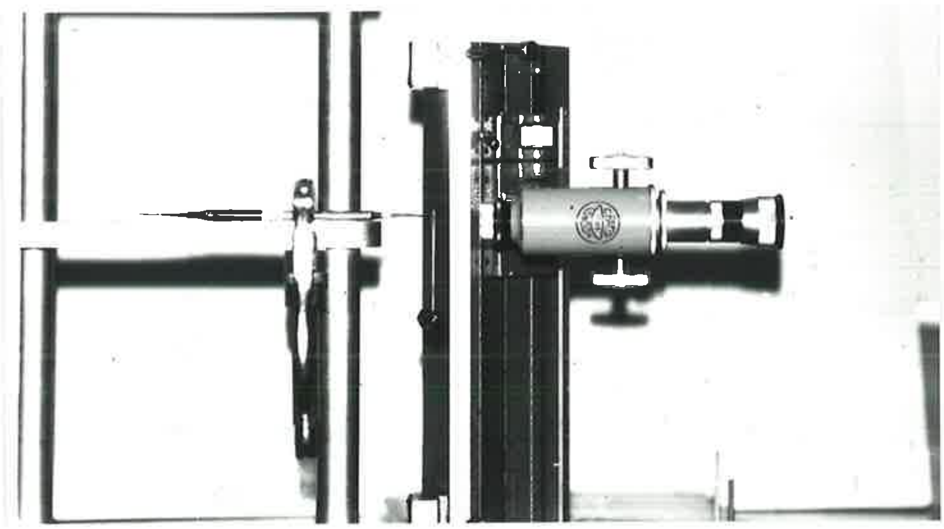


Fig. 5.29.
Dead weight tester for deflection of explorer tines.

The same seven explorers as for sections 5.3.1, 5.3.2 and 5.3.3 were used.

5.3.5 RESULTS AND DISCUSSION

The results for the different test methods are shown in Figs. 5.30 to 5.34 for the four different experimental procedures.

Ideally tine rigidity testing should be carried out using a mode which reflects the clinical use of the instrument. This would allow the formulation of a range of flexibility which is maximally suited to the functions of the instrument. Difficulty arises for dental explorers due to the fact that clinically these instruments are used for more than one function. Thus explorers are used in a different manner when examining a pit or fissure for the presence of caries than when evaluating the surface roughness of a preparation or restoration.

Aside from the properties of the component materials used for instrument manufacture, dimensional characteristics such as length, shape and thickness will influence instrument rigidity. Explorer tines are circular in cross-section and taper to a point. Their design has largely been influenced by provision of access to the areas being examined by the operator (CHARBENEAU et al, 1981).

The present standards relevant to dental explorers are the British Standard 2965:1970 (Australian Standard

Fig. 5.30. Graphic representation of horizontal displacement obtained for seven explorer tines using the British Standard Test of Mechanical Properties of Probes. Greater tine flexibility is characterised by a corresponding increase in the amount of horizontal displacement.

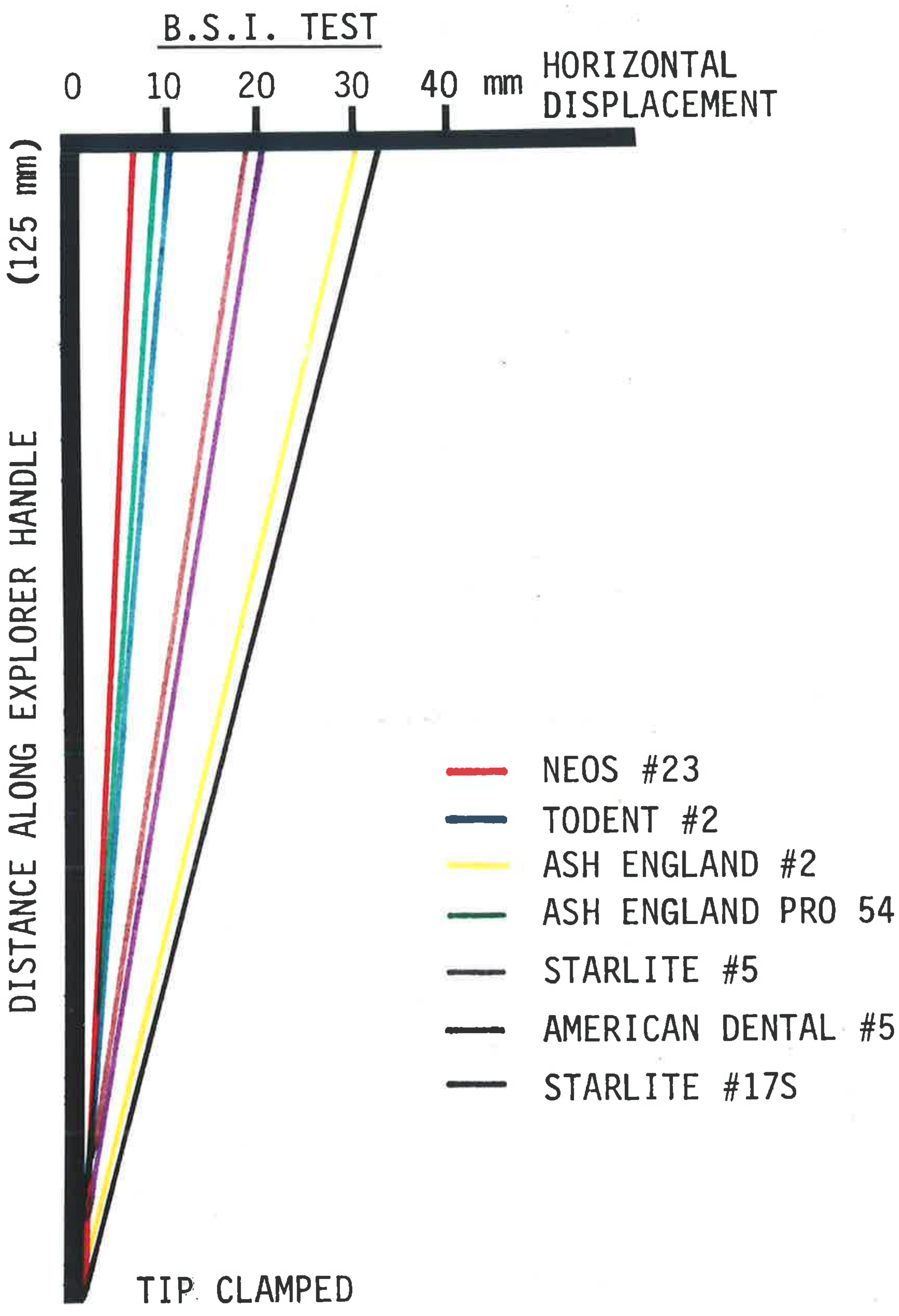

B.S.I. TEST
0
10
20
30
40
mm
HORIZONTAL DISPLACEMENT
(125 mm)
DISTANCE ALONG EXPLORER HANDLE
TIP CLAMPED
NEOS #23
TODENT #2
ASH ENGLAND #2
ASH ENGLAND PRO 54
STARLITE #5
AMERICAN DENTAL #5
STARLITE #17S

Fig. 5.31. Graphic representation of horizontal displacement obtained for seven explorer tines using the Modified British Standard Test of Mechanical Properties of Probes. Greater tine flexibility is characterised by a corresponding increase in the amount of horizontal displacement.

MODIFIED B.S.I. TEST

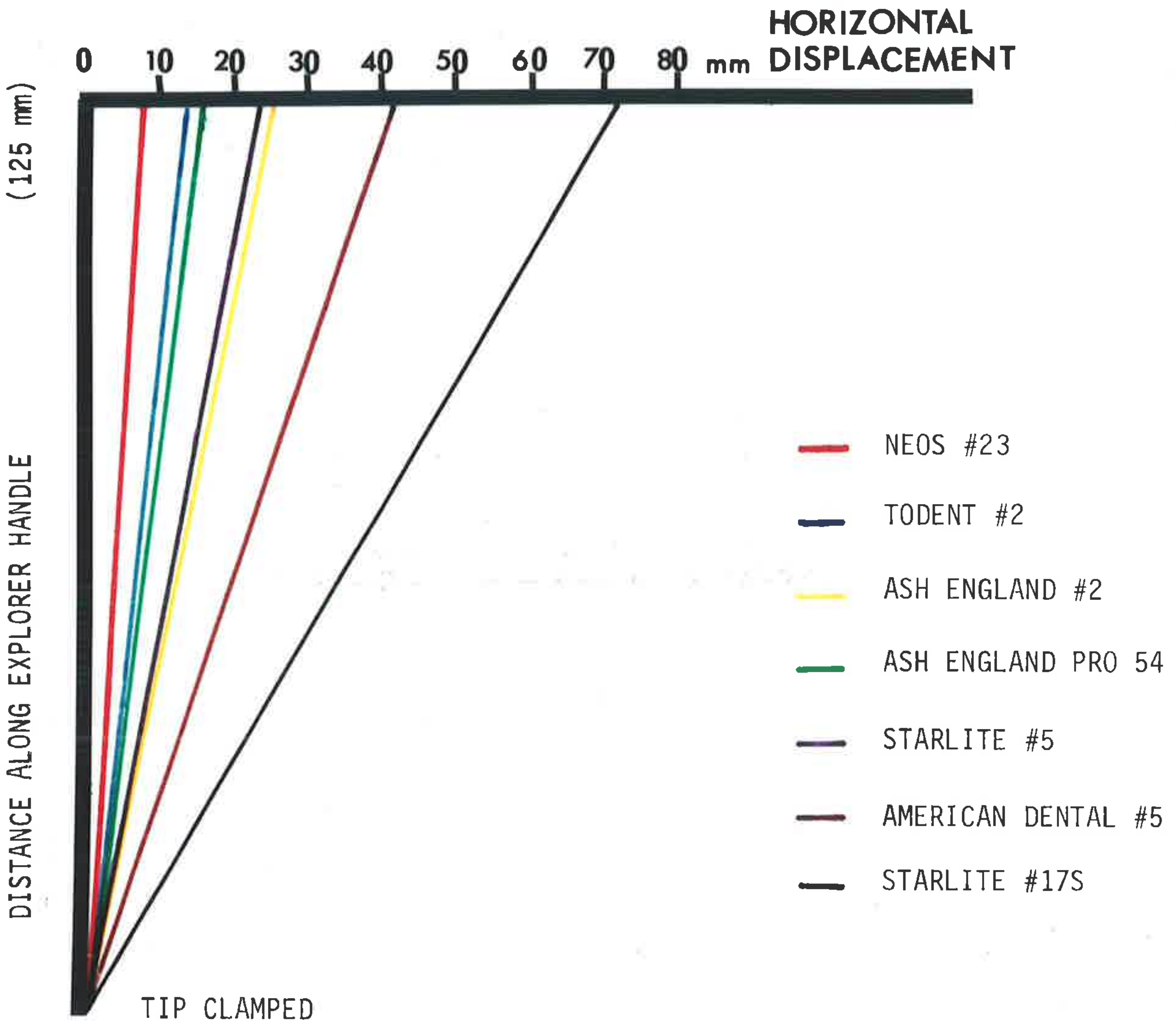


Fig. 5.32. Graphic representation of load-deflection measurements obtained for seven explorer tines using the Tinius Olsen Stiffness Tester.

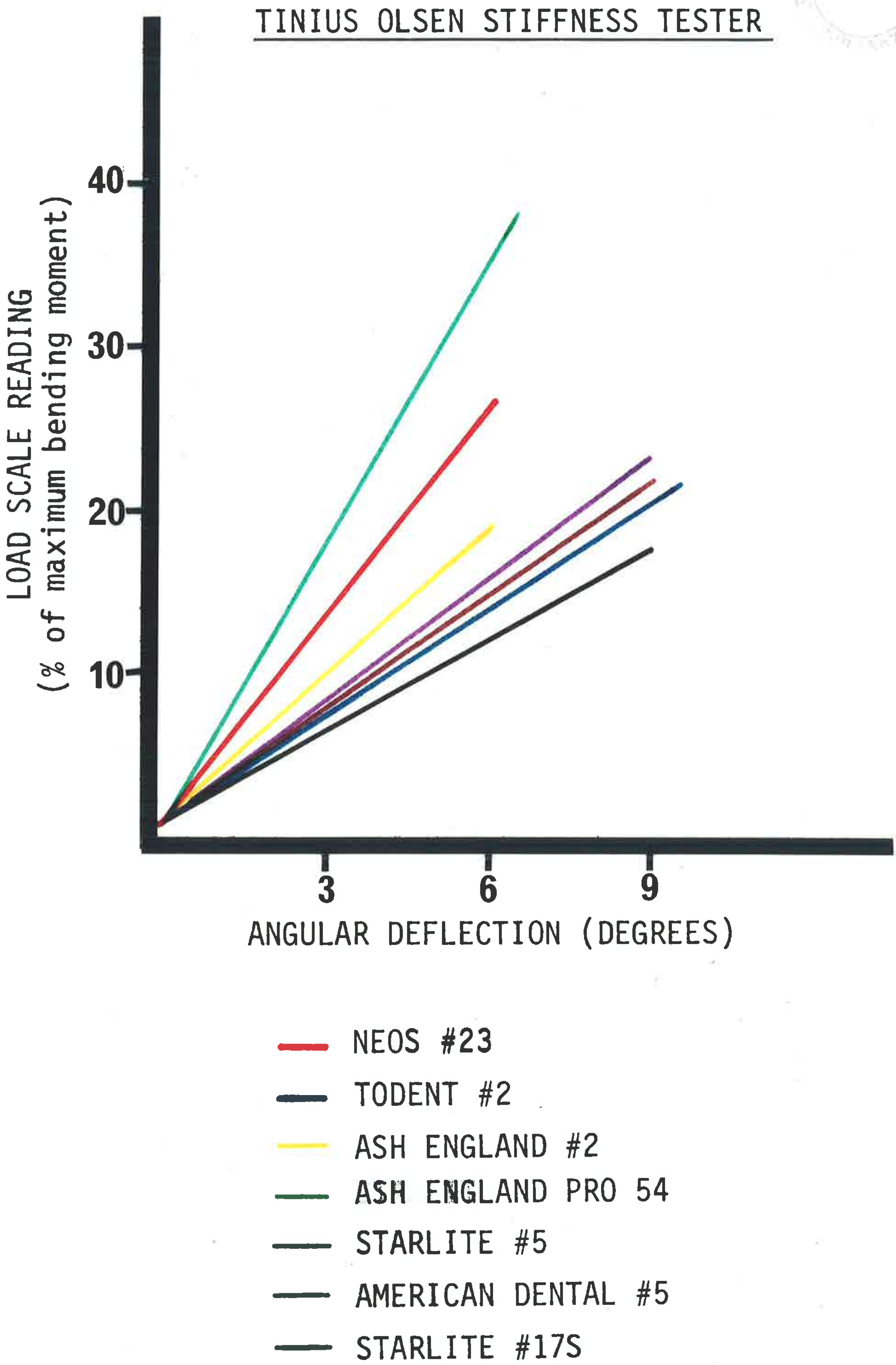

TINIUS OLSEN STIFFNESS TESTER
LOAD SCALE READING
(% of maximum bending moment)
40
30
20
10
3
6
9
ANGULAR DEFLECTION (DEGREES)
NEOS #23
TODENT #2
ASH ENGLAND #2
ASH ENGLAND PRO 54
STARLITE #5
AMERICAN DENTAL #5
STARLITE #17S

Fig. 5.33. Graphic representation of load-deflection measurements obtained for seven explorer tines using a dead weight system for loads of 10, 20 and 50 grams.

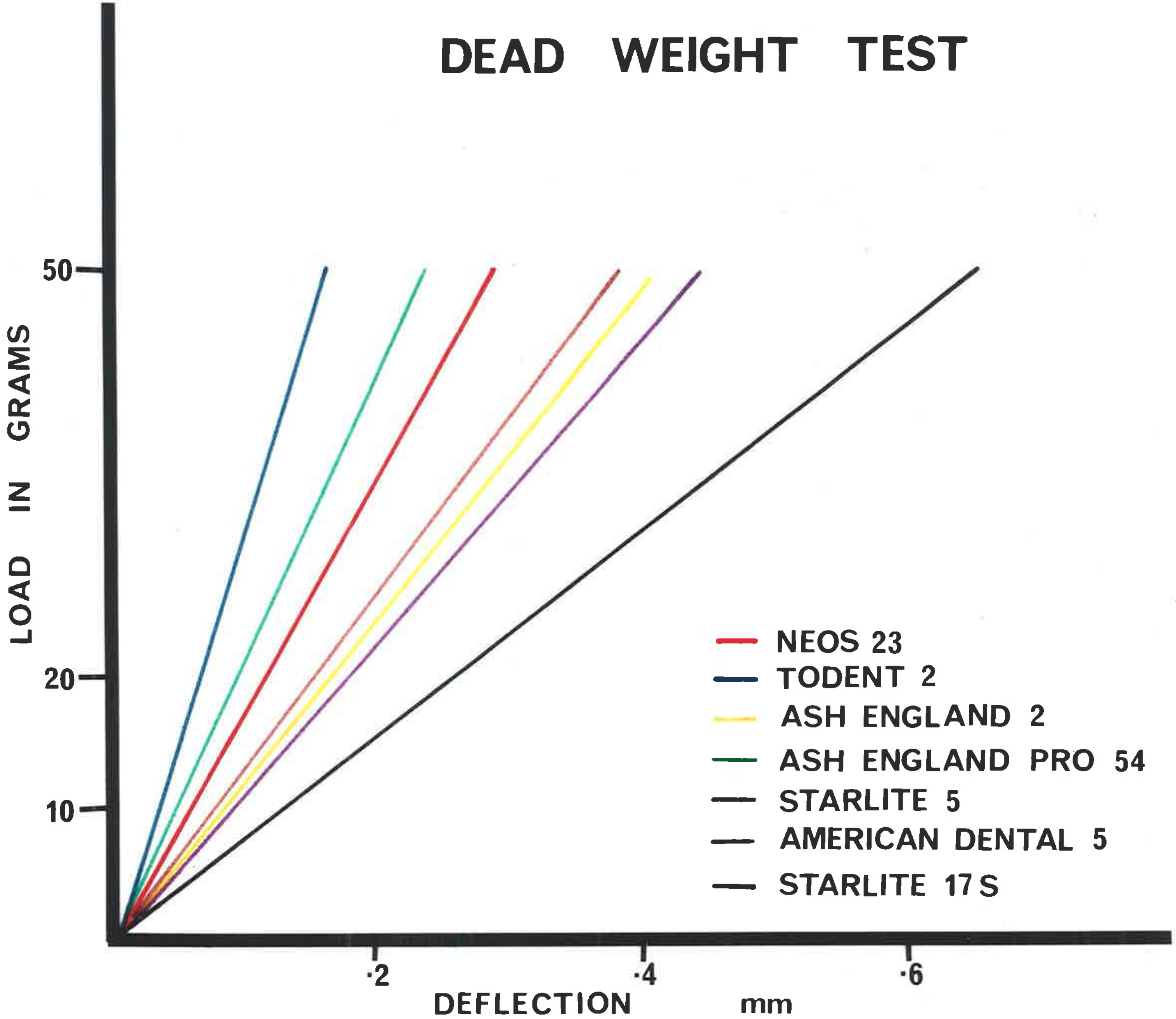
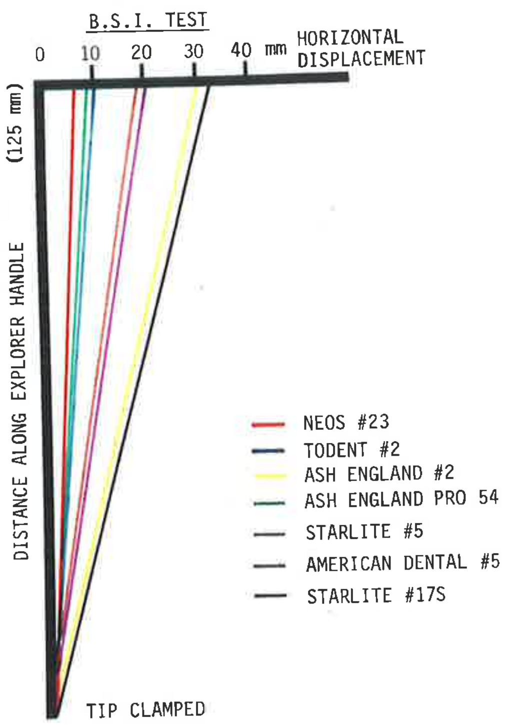
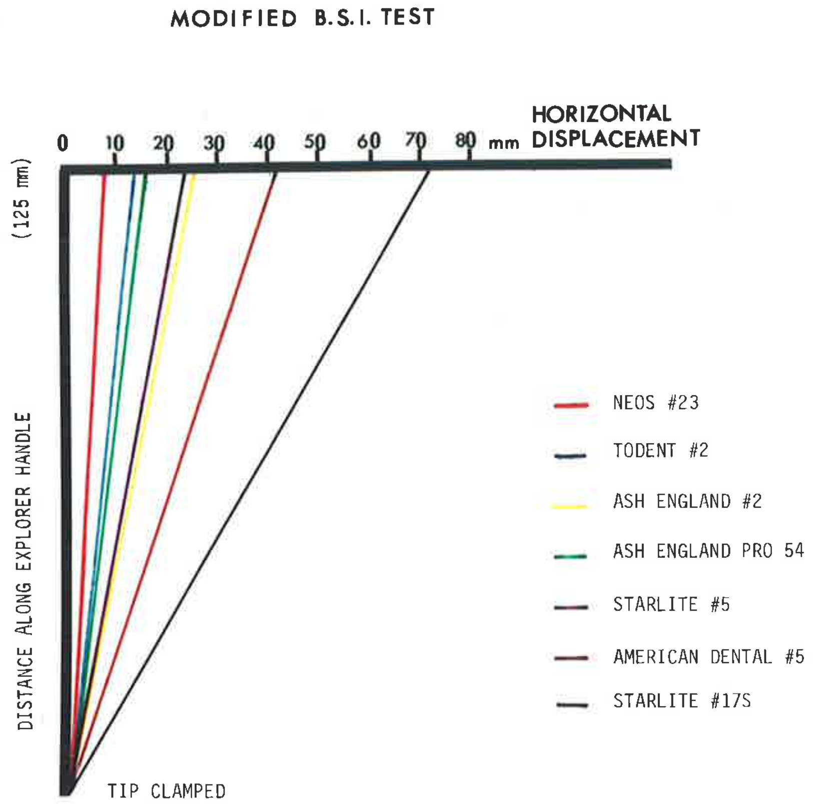

DEAD WEIGHT TEST
50
20
10
LOAD IN GRAMS
·2
·4
·6
DEFLECTION mm
NEOS 23
TODENT 2
ASH ENGLAND 2
ASH ENGLAND PRO 54
STARLITE 5
AMERICAN DENTAL 5
STARLITE 17S

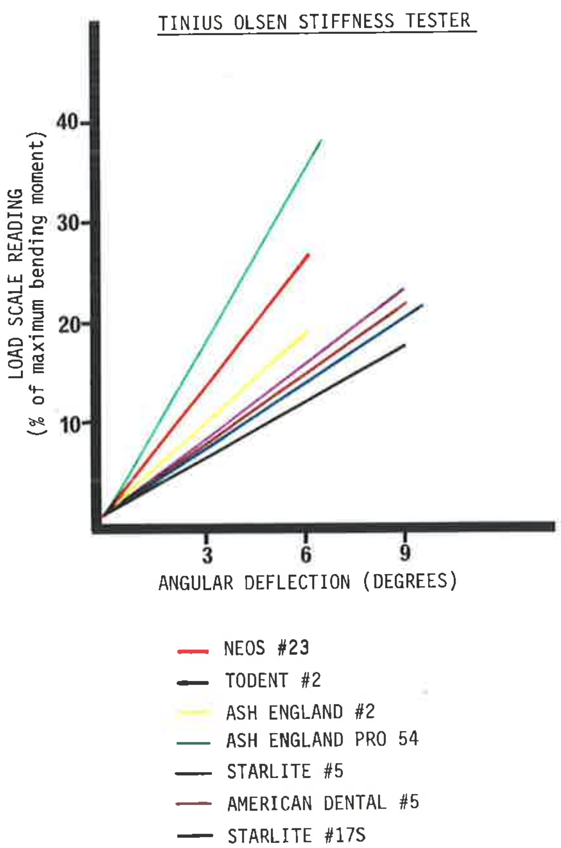
Fig. 5.34. Comparison of the four test methods used to characterise tine rigidity.



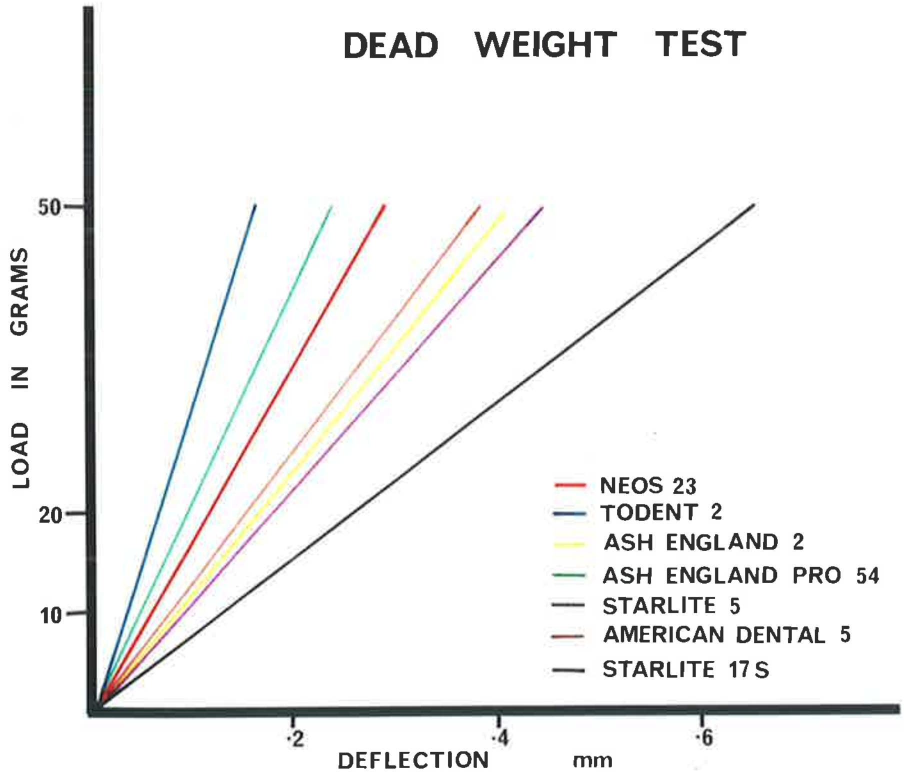
B.S.I. TEST
0 10 20 30 40 mm HORIZONTAL DISPLACEMENT
DISTANCE ALONG EXPLORER HANDLE (125 mm)
TIP CLAMPED
NEOS #23
TODENT #2
ASH ENGLAND #2
ASH ENGLAND PRO 54
STARLITE #5
AMERICAN DENTAL #5
STARLITE #17S



MODIFIED B.S.I. TEST
0 10 20 30 40 50 60 70 80 mm HORIZONTAL DISPLACEMENT
DISTANCE ALONG EXPLORER HANDLE (125 mm)
TIP CLAMPED
NEOS #23
TODENT #2
ASH ENGLAND #2
ASH ENGLAND PRO 54
STARLITE #5
AMERICAN DENTAL #5
STARLITE #17S



TINIUS OLSEN STIFFNESS TESTER
LOAD SCALE READING (% of maximum bending moment)
40
30
20
10
3 6 9
ANGULAR DEFLECTION (DEGREES)
NEOS #23
TODENT #2
ASH ENGLAND #2
ASH ENGLAND PRO 54
STARLITE #5
AMERICAN DENTAL #5
STARLITE #17S



DEAD WEIGHT TEST
LOAD IN GRAMS
50
20
10
·2 ·4 ·6
DEFLECTION mm
NEOS 23
TODENT 2
ASH ENGLAND 2
ASH ENGLAND PRO 54
STARLITE 5
AMERICAN DENTAL 5
STARLITE 17S

1086:1971) and the Draft ISO International Standard ISO/DIS 7492. The Draft ISO International Standard does not include any requirement for tine stiffness. The British Standard classifies explorer tines according to their diameter as either (1) thick, (2) medium, or (3) thin and includes a bending test (Fig. 5.25) to grade explorers as being either (1) flexible or (2) rigid.

The results of the four methods tested in this study to assess tine rigidity show that no method gave the same relative stiffness values to this series of explorers, except for the most flexible explorer, the Starlite No. 17S.

The British Standard test for tine flexibility presented difficulty in clamping the tapered tine tip so as not to allow any movement. This difficulty in gripping the tip of the instrument was apparent during the original formulation of the British Standard rigidity test, as can be seen from this extract from the minutes of the sub-committee of November 1954:

"Attention was drawn to the difficulty in bending and rigidity tests of holding the tip of probes which might have a tine as small as 1 1/2 mm.

Mr. Low agreed that this was extremely difficult but said it was the only method he had been able to devise for subjecting the probe to the sort of movement they received in use. He would however, welcome further suggestions" (GIBBONS, 1981).

In contradiction to Mr. Low's statement that the explorer is subjected to the type of movement received in use, the British Standard test for tine flexibility is singularly directionally dependent and this direction does not reflect clinical use. Further disadvantages of the British Standard test are that a parallax error may readily exist when assessing deflection, and the test appears to be influenced by the instrument handle weight.

Modification of the British Standard test for tine rigidity, so that the force is applied to the axis of the handle in a direction 90° to the form of the explorer (Fig. 5.27), did not rectify any of the disadvantages discussed above. Instead an additional disadvantage was introduced with this method in that torsion was applied to the explorer tine rather than the desired deflective load.

The Tinius Olsen stiffness tester allows the tine to be positioned so as to simulate the type of movement received in clinical use. The disadvantage of this method is that in applying the deflective force at a point 2 mm from the tine tip, only a small angular deflection (6 - 9 degrees) is required before the tine slips off the platform which applies the force. This therefore limits the test range and this test requires qualification, in that the deflective force is not applied at a constant distance of 2 mm from the tine tip. To circumvent this problem, future studies using the Tinius Olsen Stiffness Tester could employ a modification whereby a "chain and bucket" is attached to the machine's contact plate. The explorer tine tip is then positioned into the "bucket" (Fig. 5.35). This modification would closely simulate a clinical deflective force being applied at the tine tip.

The dead weight system for assesing tine deflection was able to discriminate between explorers in a manner simulating lateral movement of the explorer at light loads. Of all the test methods for tine rigidity examined in this study, the dead weight system was the method which most closely reflected the clinical use of an explorer as an instrument for assessing surface roughness.

In contrast to the test methods examined in this study, one explorer manufacturing company* has designed its own "in-house" deflection tester (Fig. 5.36) (GUTHRIE, 1981). This test method applies a vertical force to the explorer tine point and a measurement is made of the amount of deflection per unit of force as well as the amount of permanent deflection following removal of the applied force. This test reflects the clinical use of an explorer as an instrument for detecting pit and fissure caries, but bears no correlation to the type of movement when used as an instrument for assessing surface roughness.

* American Dental Mfg. Co., Missoula, Montana, USA

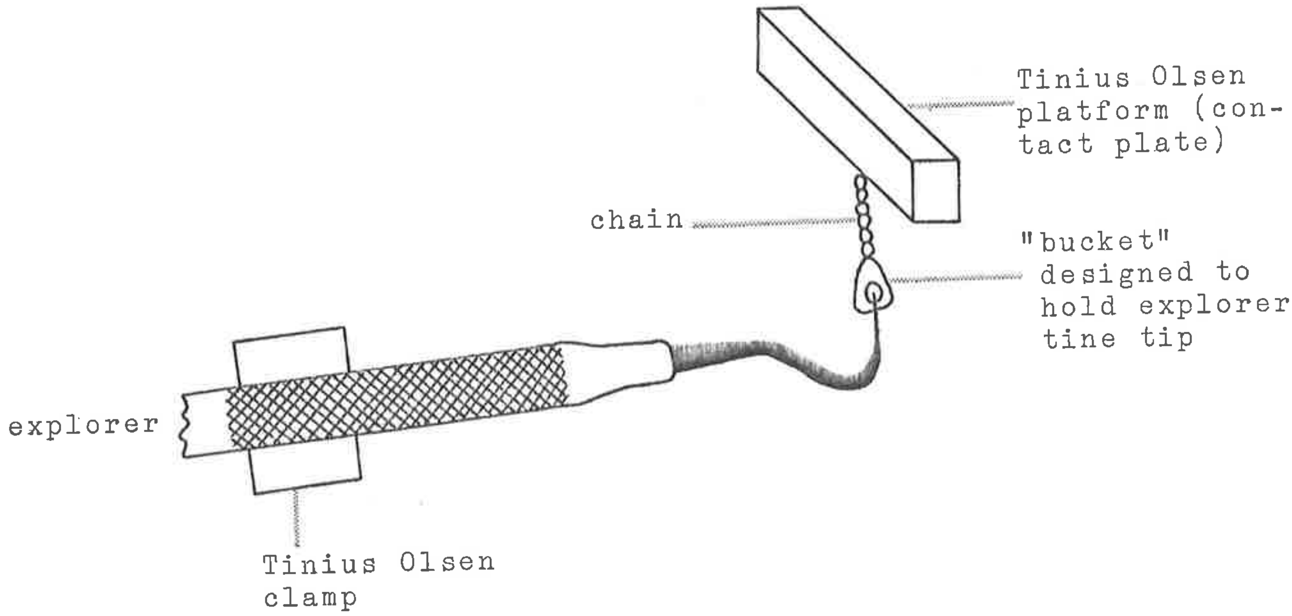


Fig. 5.35. Diagrammatic representation of a possible modification for the Tinius Olsen Stiffness Tester in order to apply a deflective force at the explorer tine tip.

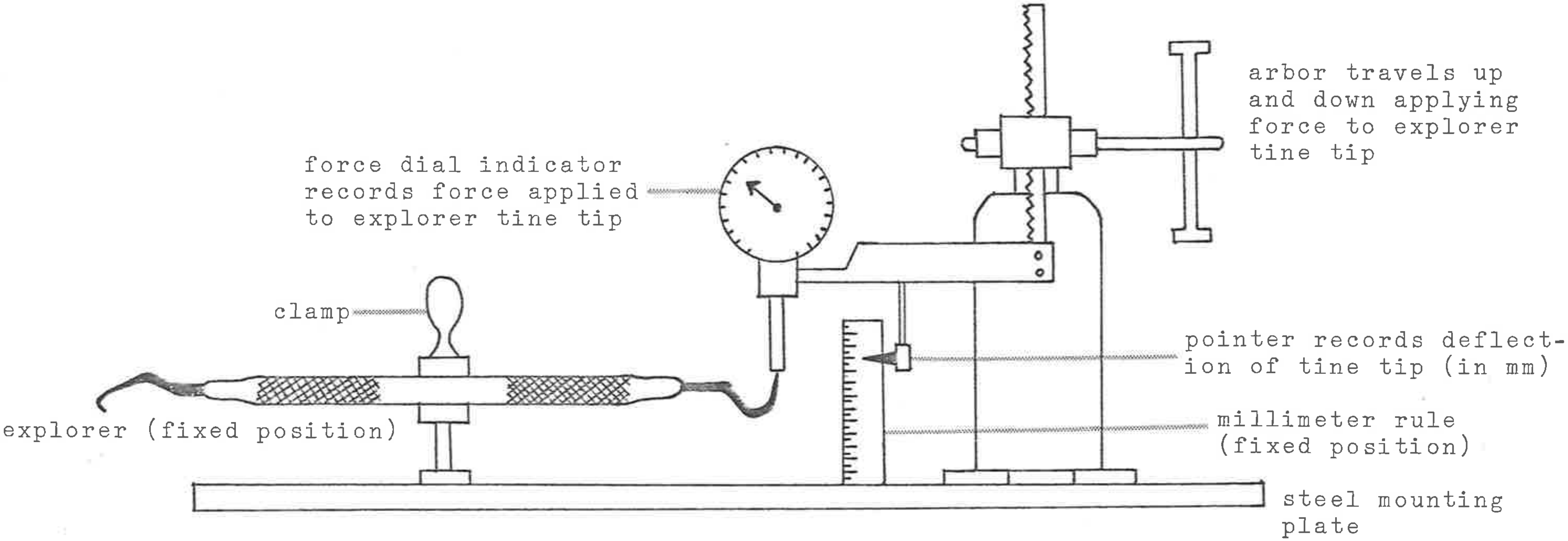


Fig. 5.36. "In-house" deflection tester used by the American Dental Manufacturing Company (GUTHRIE, 1981).

IN SUMMARY

(1) Tine rigidity testing should be carried out using a mode which reflects the clinical use of the instrument.

(2) For assessment of surface roughness, the British Standard test method does not simulate clinical conditions, whilst the dead weight system most closely simulates the clinical use of an explorer in assessing surface roughness.

(3) A modification of the T.O. test method to apply a lateral force at the explorer tine tip to characterise tine rigidity warrants further study.

(4) Consideration should be given to the formulation of two different rigidity test methods for dental explorer tines. One for the function of surface roughness assessment, and the other for caries detection.

5.4 TO ASCERTAIN THE CONDITIONS OF USING AN EXPLORER

Whilst using a dental explorer for assessing surface roughness four parameters; load applied to the explorer tine, direction of movement of the explorer, speed of movement of the explorer, and finger loads on the explorer handle, were examined.

5.4.1 LOAD APPLIED TO AN EXPLORER TINE

5.4.1.1 Materials and Methods

Enamel and dentine specimens, prepared with a Fis L20 diamond bur in an air turbine at approximately 300,000 r.p.m. with water spray, were mounted side by side on a metal beam. Strain guage sensors were attached to this beam and these in turn were connected to a chart recorder (calibrated using dead weights) (Fig. 5.37).

Forty-six operators participated in this study, the majority (36) being qualified dentists, the others, final year dental students. Each operator was asked to "examine the two surfaces of tooth structure with this explorer and decide if one is smoother than the other". The explorer used was an American Dental Amflex I sickle explorer. White noise, delivered via headphones was used to block any auditory input. A chart recording was made for each operator from which the minimum and maximum loads applied to the specimen by each operator were calculated (Fig. 5.38).

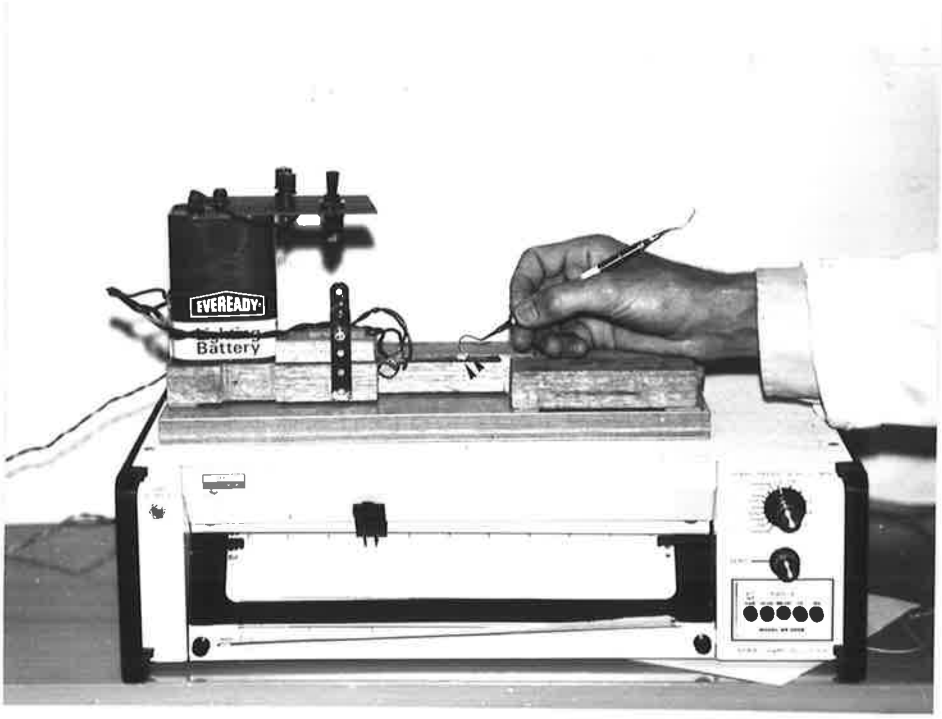


Fig. 5.37. Apparatus used for the assessment of load applied to an explorer tine.

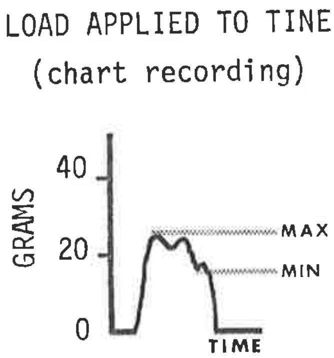


Fig. 5.38. A chart recording obtained for assessment of load applied to an explorer tine.

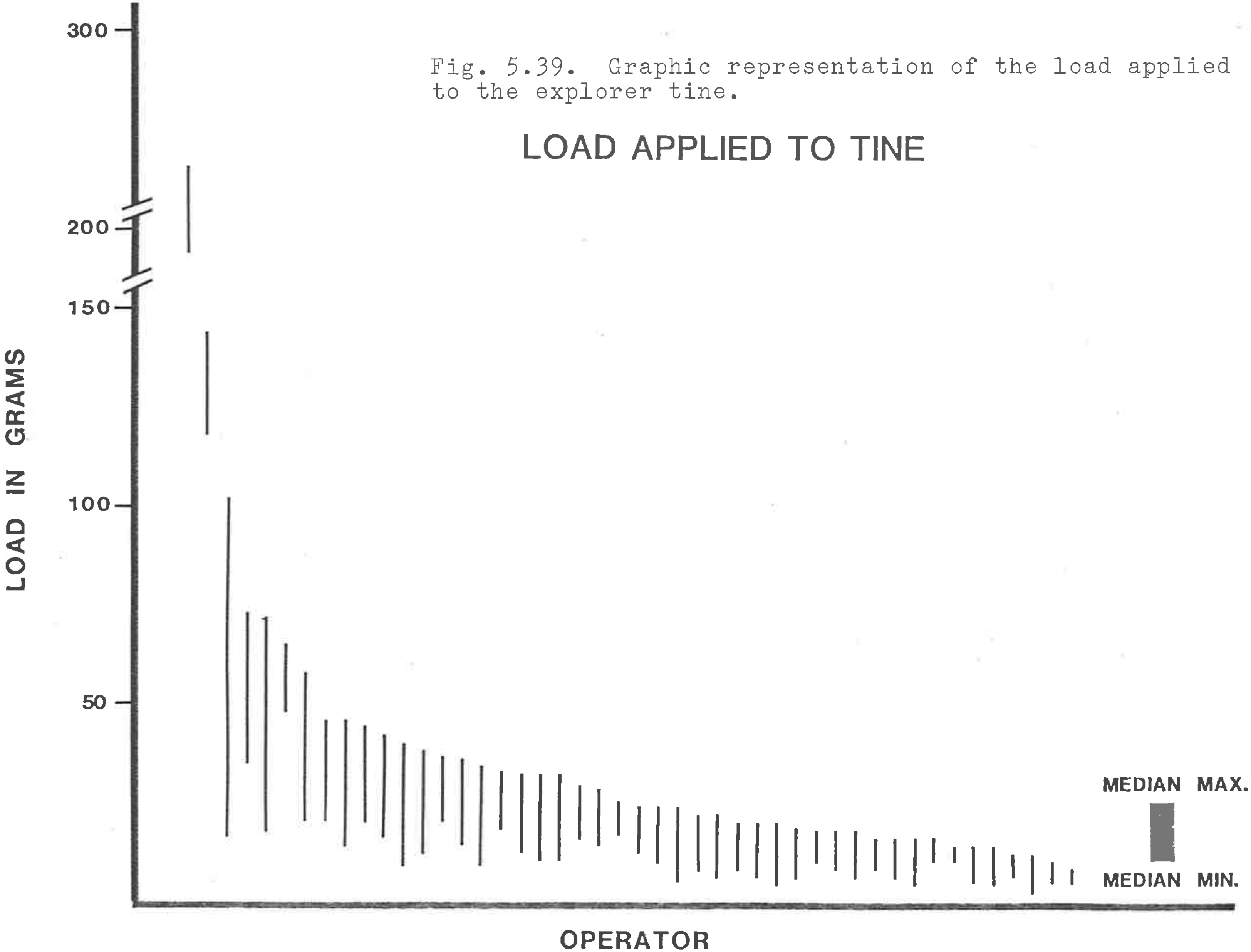


Fig. 5.39. Graphic representation of the load applied to the explorer tine.

5.4.1.2 Results and Discussion

The results for the forty-six operators who participated in this study are shown in Fig. 5.39.

The loads ranged from 2 gm to 266 gm with the median minimum load at 10 gm and the median maximum load at 25 gm. The results demonstrate a great variation between operators in the pressure placed on the explorer tine tip.

In order to initiate explorer tine vibration it is necessary to apply a deflective force to the explorer tine. The surface being examined provides the resistance to this deflective force by a combination of the vertical pressure and surface hardness. The effect of the tine tip cutting into the surface being examined has been discussed in Section 5.1.

The chart recordings obtained (Fig. 5.38) show that the pressure applied to the explorer tine by the operator varies during use of the explorer. This can be explained in terms of the existence of a bio-feedback relationship maintaining sufficient load to initiate tine vibration and a minimum load to allow the tip to follow surface texture (roughness). It has been suggested that exploratory movements function to isolate and enhance components of stimulation which specify the shape and other characteristics of the object being examined (GIBSON, 1962).

The experimental method used for this study incorporated test specimens of dentine and enamel.

These two surfaces have different hardness values, and this may have contributed to the range of variability obtained in the results. An alternative experimental procedure would have been one in which a surface roughness test plate was used for the test specimens.

5.4.2 DIRECTION OF MOVEMENT OF EXPLORER

5.4.2.1 Materials and Methods

At the time of determination of load applied to the explorer tine discussed in the previous section, the initial direction in which the explorer was used by the operator was also recorded.

The direction in which the explorer was used was classified as follows (Fig. 5.40):

(a) vertically drawn away from the operator

(b) vertically drawn towards the operator

(c) laterally and to the right

(d) laterally and to the left.

5.4.2.2 Results and Discussion

The results for all operators (forty-six operators) and for the right-handed operators only (forty-two operators) are shown in Figs. 5.41 and 5.42 respectively. A comparison between the two groups is illustated in Fig. 5.43.

The results demonstrate that the majority of the operators used the explorer in a direction either laterally and to the right or drawn towards the body.

There are three possible reasons to explain why the operators favoured these directions of explorer movement:

1. The experience of the operators has indicated that these directions provide the greatest tactile input to the explorer.
2. The handedness of the operator favours these directions. The majority of the operators in this study were right-handed operators.
3. The design of the sickle explorer is such that it is easiest to use this explorer in these two directions.

Of interest to this study is that the British Standard Test of Mechanical Properties of Probes to characterise tine rigidity (discussed in Section 5.3) tests explorers in a direction equivalent to that vertically away from the operator (Fig. 5.25); this direction being least preferred by the operators. The results of this study therefore cast doubt on the validity of the existing British Standard test procedure for load direction to characterise tine rigidity since it does not reflect the clinical use of the instrument for the purpose of surface roughness evaluation.

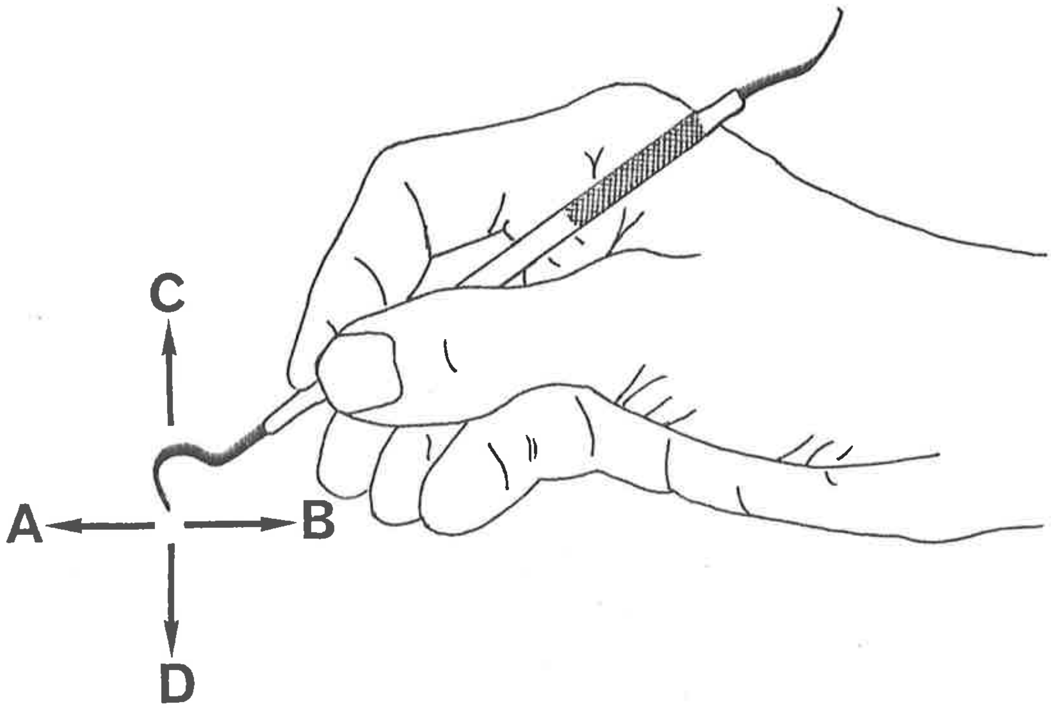


Fig. 5.40. Classification of direction of movement of the explorer during use:
A vertically drawn away from operator
B vertically drawn towards operator
C laterally and to the right of operator
D laterally and to the left of operator

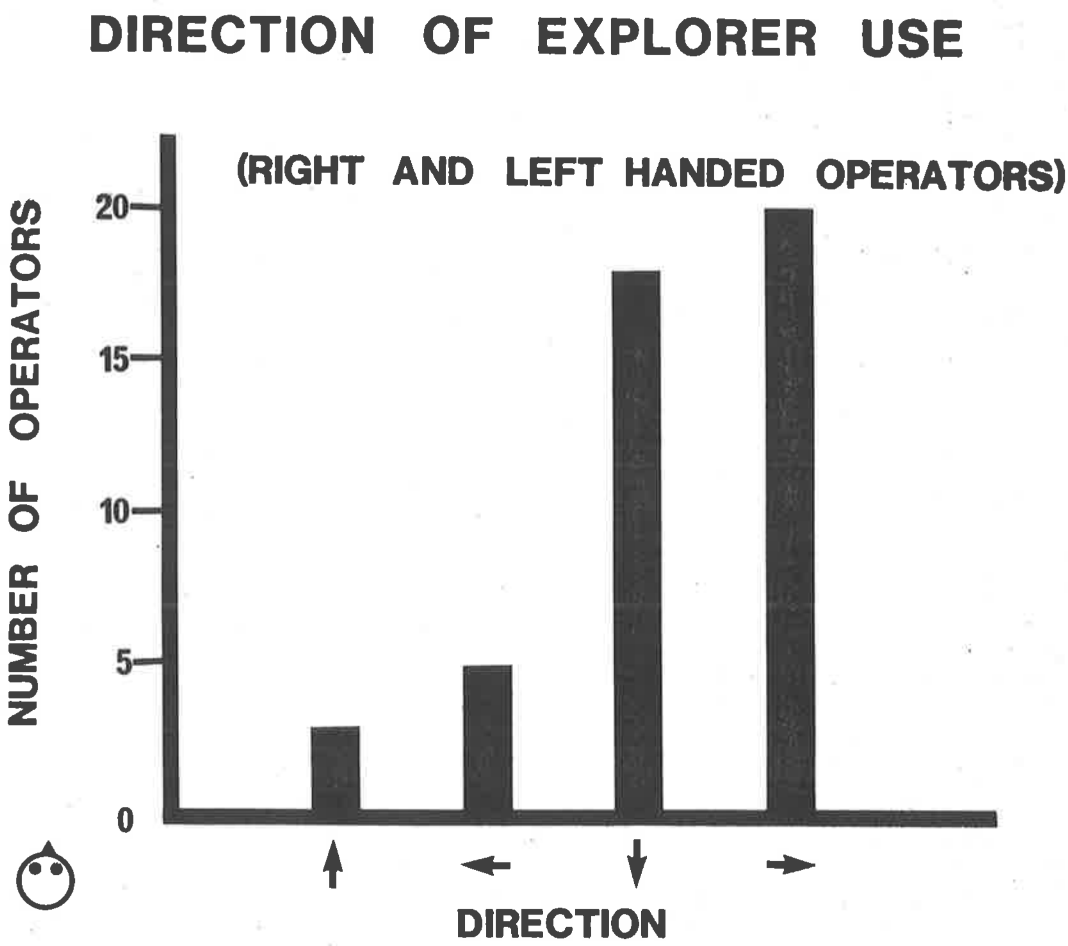


Fig. 5.41. Direction of explorer use for all operators (46).

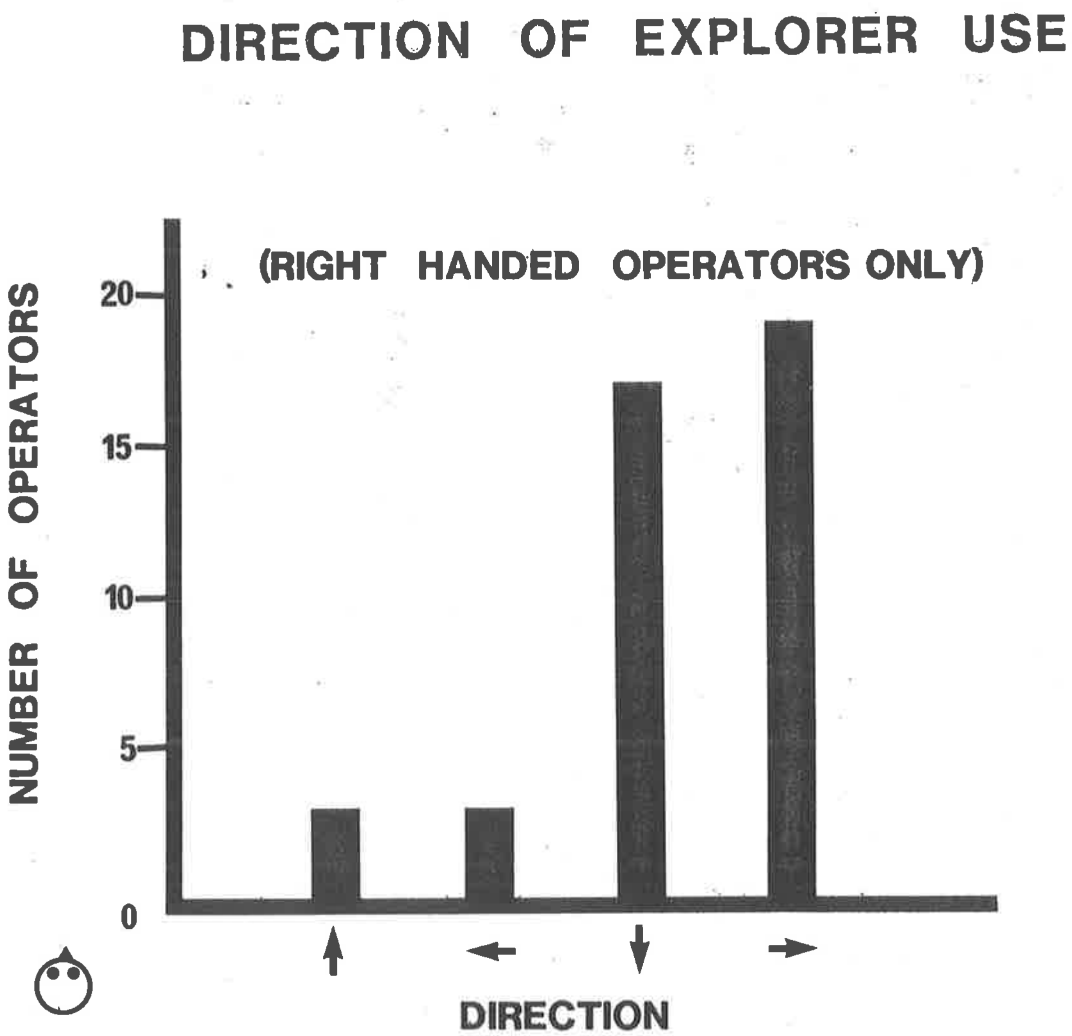


Fig. 5.42. Direction of explorer use for right handed operators only (42).

DIRECTION OF EXPLORER USE

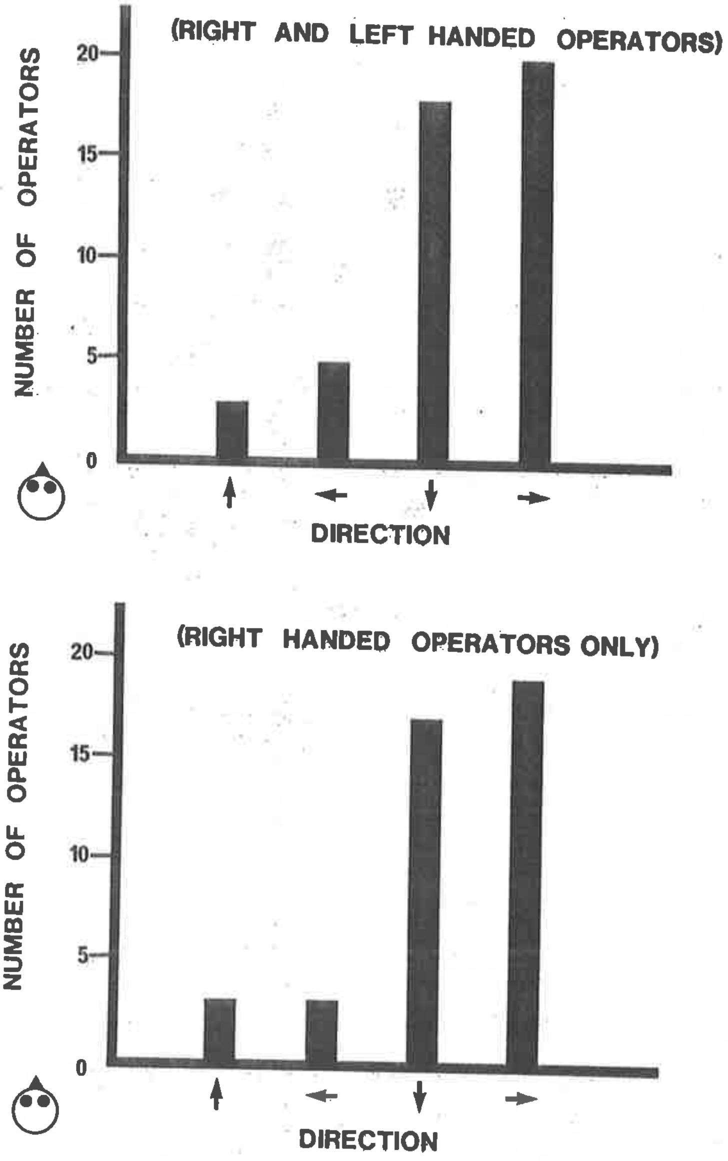


Fig. 5.43. Comparison of direction of explorer use.

5.4.3 SPEED

5.4.3.1 Materials and Methods

A Frasaco plastic tooth* with a prepared Class I cavity (surface prepared with a carbide fissure bur**) was fitted with two metal electrodes on the floor of the cavity 4.4 mm apart. An American Dental Amflex I sickle explorer was electrically coupled between these electrodes to a chart recorder (Fig. 5.44). The same operators as for Sections 5.4.1 and 5.4.2 participated in this study. Each operator was asked to "examine the tooth surface between the two metal marks to see if the surface is of even roughness, by moving the explorer from one end of the cavity to the other". White noise, delivered via headphones was used to block any auditory input. A chart recording was made for each operator (Fig. 5.45).

The speed of movement of the explorer between the electrodes was calculated using the formula:

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

5.4.3.2 Results and Discussion

The results for the forty-six operators are shown in Fig. 5.46. The mean speed was 3.5 mm/sec with

* Frasco Co., West Germany
** A.D. International Co., London

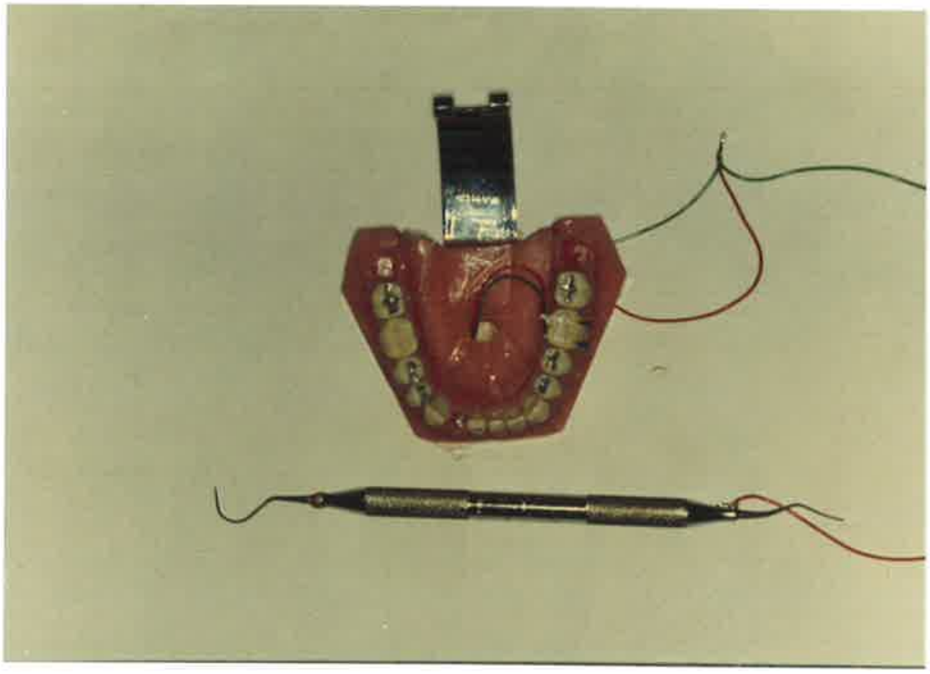


Fig. 5.44. Apparatus used for determination of speed. Metal electrodes on floor of the cavity (arrows).

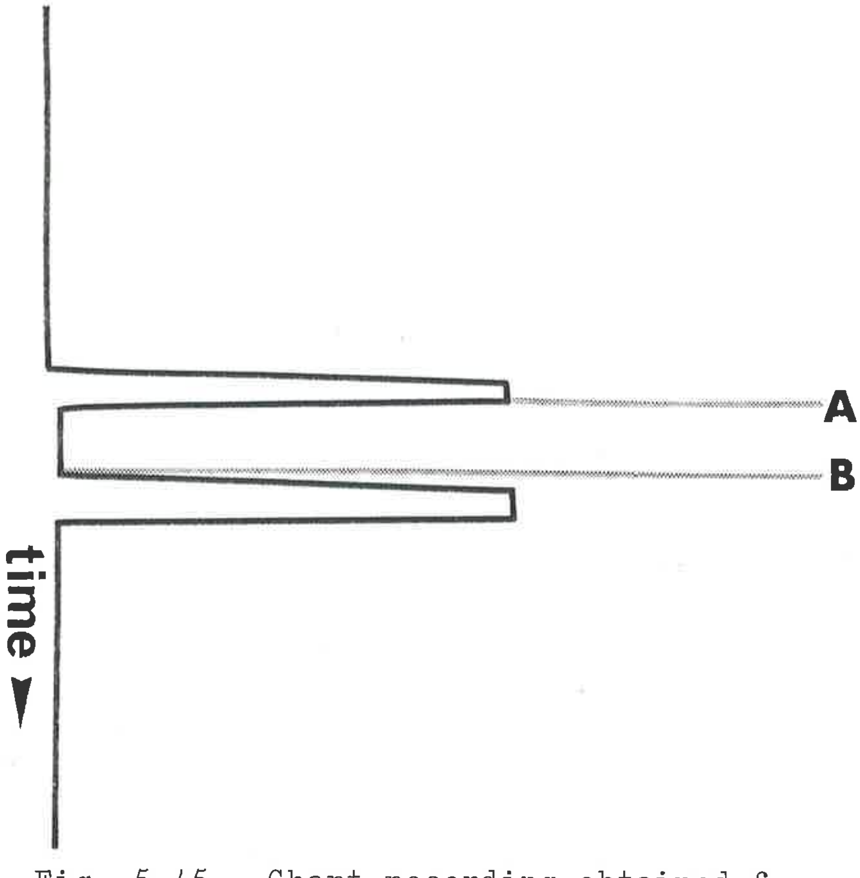


Fig. 5.45. Chart recording obtained for assessment of speed. (A) Point at which explorer leaves edge of first electrode. (B) Point at which explorer contacts edge of second electrode.

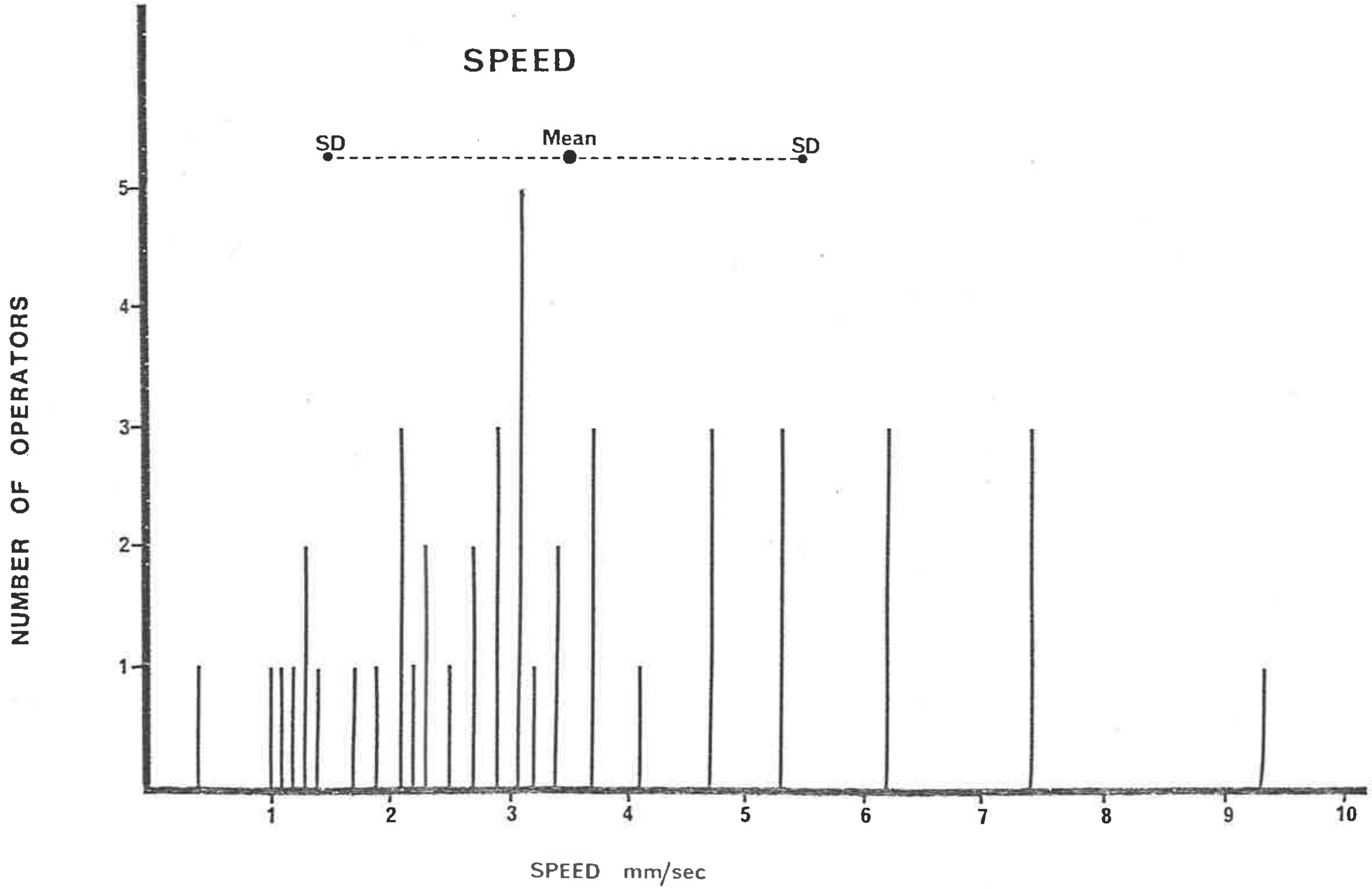


Fig. 5.46. Graphic representation of the speed at which an explorer was used.

a standard deviation of 2.0 mm/sec. Operator variability ranged from 0.4 mm/sec up to 9.3 mm/sec.

The results of this study do not take into consideration the constancy of the speed and only represent an average value over a small fixed distance.

It has already been shown that subjects using their fingers to determine roughness do not maintain a constant speed (KATZ, 1925). Since the same perceptual pathways would be involved when using an instrument such as a dental explorer to determine surface roughness, constancy of speed would not be expected. It therefore seems that a bio-feedback relationship exists which takes into simultaneous account surface texture and hand speed. However, Lamb (1982) observed that tactile thresholds using the fingers were virtually unaffected by changes in the velocity of movement.

The interest in the speed of use is for the evaluation of a possible relationship of this speed with the surface roughness peaks to produce a vibration frequency of the tine tip.

5.4.4 FINGER LOAD

5.4.4.1 Materials and Methods

A simulated explorer handle was triangular in cross section thus providing three flat surfaces onto which the thumb, index and middle fingers made contact. Strain guage sensors were placed on a short suspended metal beam across one of the three finger positions (Fig. 5.47). To this explorer handle was fitted an American Dental Amflex I sickle tine which could be rotated relative to the strain guage for the series of finger positions.

Sixteen operators (13 being qualified dentists, the remainder senior dental students) participated in this study and whilst assessing the surface roughness of a standard metal roughness plate (Rugotest plate No. 101/32*; Ra value 0.8 µm), a chart recording was made consecutively for each of the three contacting fingers (thumb, index and middle) from which minimum and maximum finger load measurements were made (Fig. 5.48).

5.4.4.2 <u>Results and Discussion</u>

The results are shown in Figs. 5.49 and 5.50. For the index finger the median maximum load was 129 gm and the median minimum load was 62.2 gm. For the middle finger the median maximum load was 151.5 gm and the median minimum load was 58.4 gm. For the thumb the median maximum load was 110 gm and the median minimum load was 62.5 gm.

These results illustrate great operator variability although there was a tendency for a balance between either heavy or light groups of finger loads for

* Pierre Roch Ltd., Rolle, Switzerland

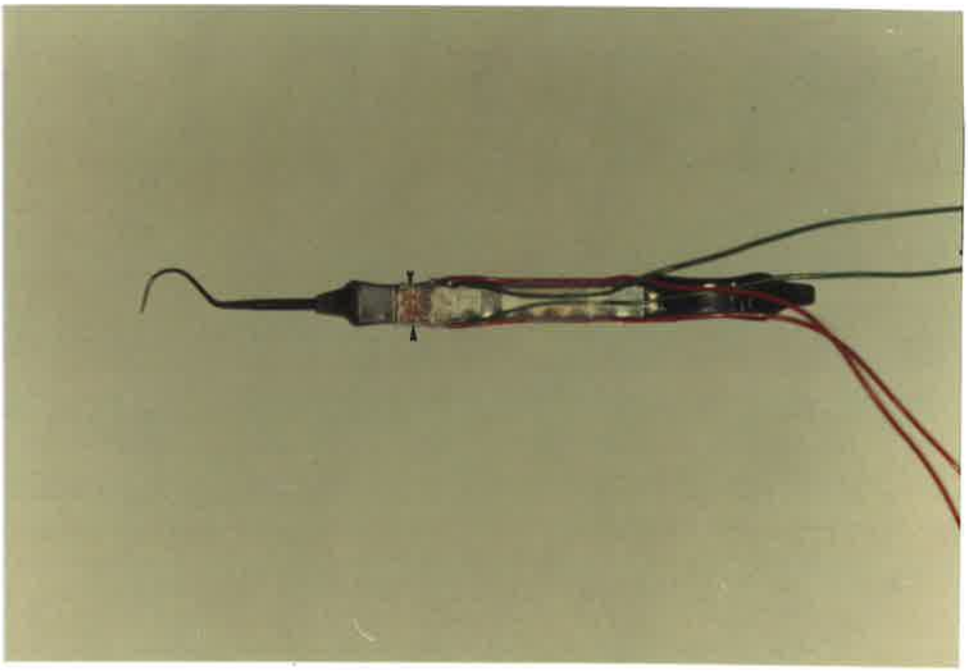


Fig. 5.47. Simulated explorer handle fitted with strain gauge transducers (arrows) used to evaluate operator finger load.

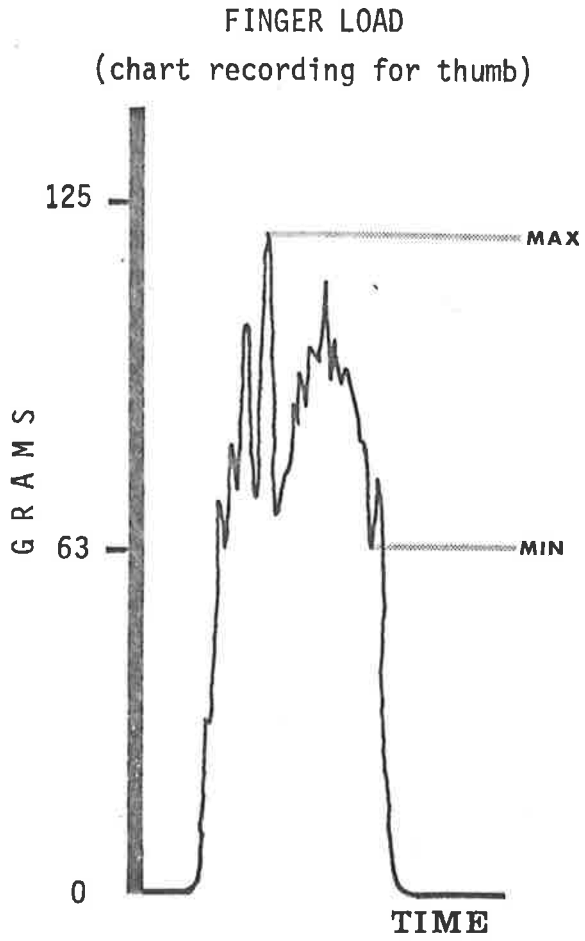


Fig. 5.48. Example of a "finger load" chart recording obtained for an operator's thumb.

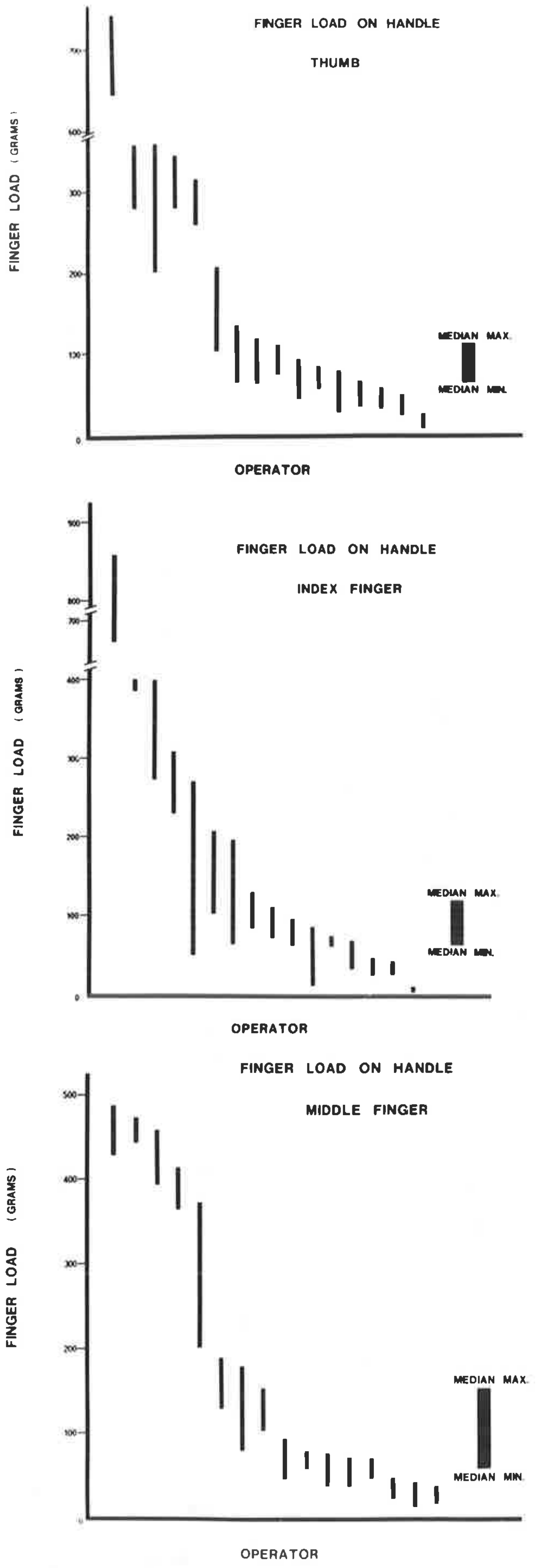
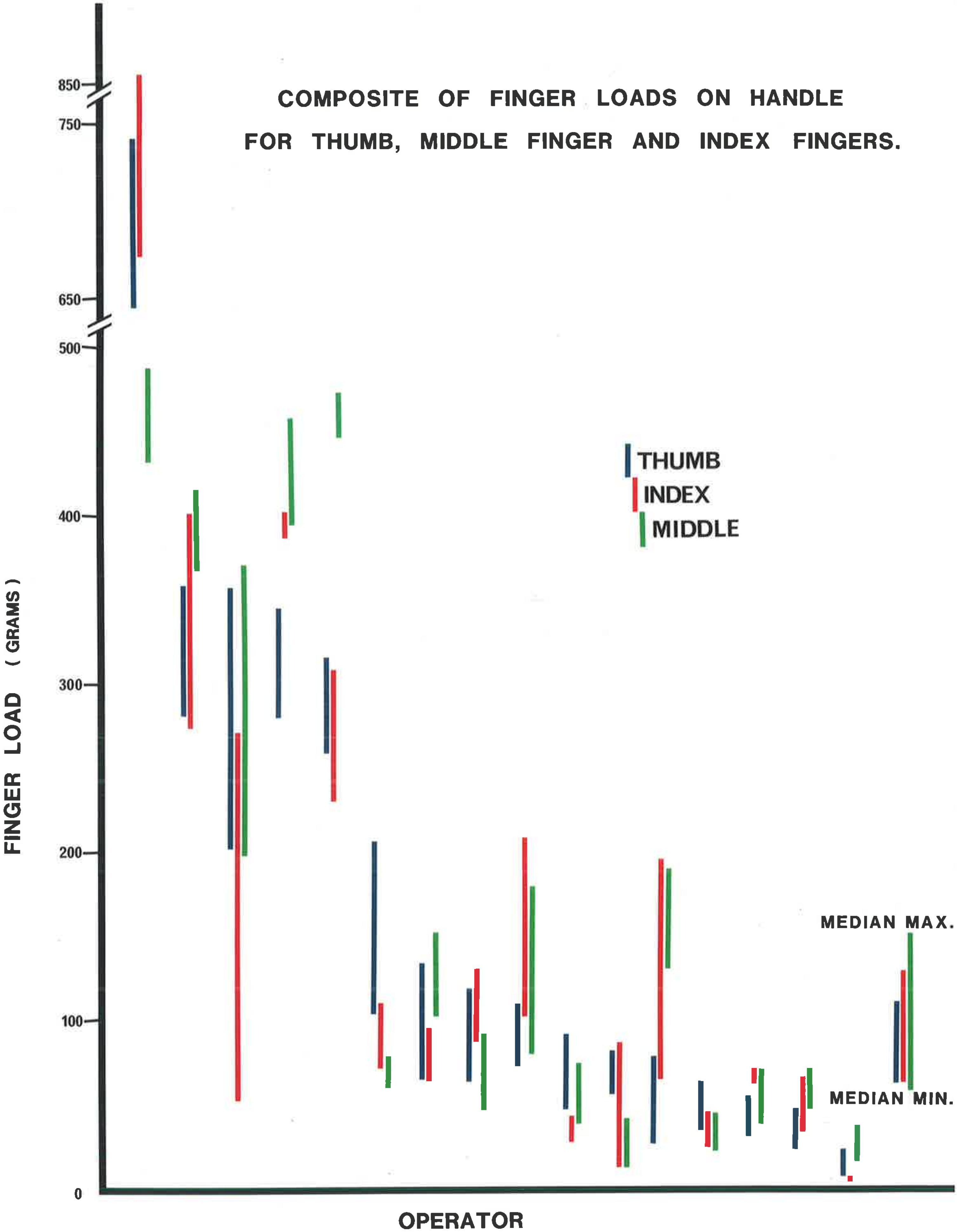


Fig. 5.49. Graphic representation of finger load applied to a simulated explorer handle for the thumb, index and middle fingers.


COMPOSITE OF FINGER LOADS ON HANDLE
FOR THUMB, MIDDLE FINGER AND INDEX FINGERS.
THUMB
INDEX
MIDDLE
MEDIAN MAX.
MEDIAN MIN.
FINGER LOAD (GRAMS)
OPERATOR
850
750
650
500
400
300
200
100
0

individual operators, but four exceptions to this were noted.

An effect of increasing the finger load is to increase the compression of the contacting soft tissues. This increases the tissue elasticity and consequently affects the vibration transmission throughout the respective finger tissues (KEIDEL, 1968). Verrillo (1966a) found that the threshold for vibration decreased as the depth to which a vibratory contactor was pressed into the skin was increased. He proposed that this was probably due to the closer proximity of the source of vibration and the deeper lying Pacinian corpuscles responsible for vibration detection.

Darian-Smith and Oke (1980) monitored the responses to vibratory stimuli in the mechanoreceptive afferent fibres of the monkey's finger pad, and found that varying the radial force in the range 20 - 60 g wt. did not significantly modify the pattern of discharge in the responding fibre populations.

The chart recordings obtained in this study (Fig. 5.48) indicate a bio-feedback response where the operator continually varies the grip on the instrument.

5.4.5 SUMMARY

This section of the study was designed to define the average conditions of using an explorer. The parameters evaluated were the load applied to a tooth by an explorer, the direction in which an explorer is moved, the speed of use of an explorer and the finger load applied to an explorer handle. The definition of these parameters is necessary in order to carry out controlled studies on vibration transmission through an explorer.

The general outcome of this study was that during examination of surface roughness a bio-feedback mechanism exists which regulates the load applied to the tooth, the speed, and the finger load applied to the handle.

The results showed great variation between individuals in the way explorers were handled:

1. The load under the tip ranged from 2 gm to 266 gm with 43.5% of operators preferring to move the instrument laterally (to the right).
2. The tip speed varied from 0.4 mm/sec to 9.3 mm/sec.
3. The finger loads varied from 4.2 gm to 857 gm for the index finger, from 7 gm to 743 gm for the thumb and from 12.5 gm to 486 gm for the middle finger, although there was a tendency for a balance between either heavy or light finger loads for individual operators.

The feasibility of bio-feedback teaching aids to maximise perceptual skills from instruments for selected undergraduate students warrants study.

CHAPTER VI

PHYSIOLOGICAL PARAMETERS

CHAPTER VI

PHYSIOLOGICAL PARAMETERS

6.1 INSTRUMENT GRIP

6.1.1 MATERIALS AND METHODS

To assess instrument grip each operator was asked to hold an American Dental Amflex I sickle explorer as he/she would during clinical use for detecting surface roughness. A photograph was taken of the finger positions on the explorer handle. The hand grips were subsequently divided into three types; a classical pen grip, a modified pen grip and other forms (according to Makinson and Hume, 1982).

6.1.2 RESULTS

Of the forty-six operators that participated in this study 87% preferred to use the classical pen grip, 11% used the modified pen grip, and 2% used other grip forms (Fig. 6.1).

6.1.3 DISCUSSION

Makinson and Hume (1982) found that dental students who preferred the classical pen grip or the modified pen grip for a dental handpiece, tended to be those students in the higher clinical grades in comparison with those students who had unusual handpiece grips. Overall, they found that students preferred a modified pen grip for the dental handpiece. The present study found that the

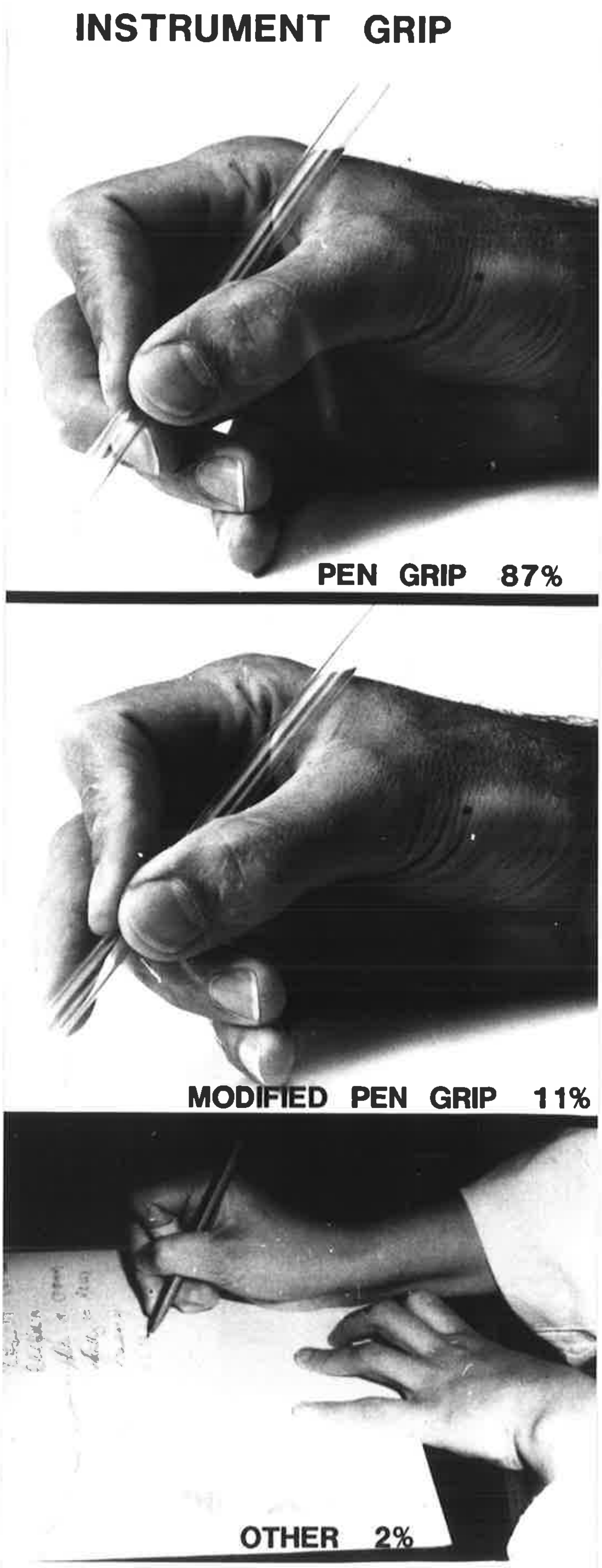


Fig. 6.1. Operator preference for instrument hand grip.

grip most preferred for a dental explorer was the classical pen grip.

Instrument grip classification would have relevance to controlled vibration studies for standardisation of vibration measurements in instrument handles.

6.2 AREA AND SITE OF TISSUE CONTACT

6.2.1 MATERIALS AND METHODS

The area and site of tissue contact was evaluated using the same method as for instrument grip, but in this instance the explorer handle was coated with black paint. The areas of tissue contact on the respective fingers were photographed.

6.2.2 RESULTS AND DISCUSSION

The average finger contact areas are shown in Fig. 6.2. These were as follows:

On the middle finger the contact area was oval-shaped and on the medial superior aspect at a point in line with the base of the finger nail.

The thumb contact was an elongated oval-shape on the palmar surface and at an oblique angle to the midline of the thumb, and extending from just below the tip down to approximately half the thumb length.

The index finger contact was of a rectangular shape and on the palmar surface extending from the tip of the finger either along the midline or at an oblique angle to just above the first phalanx.

There was individual operator variation of the area and site of tissue contact (Figs. 6.3, 6.4, 6.5), the middle finger exhibiting the greatest variability.

In relation to the effect of area of contact on vibration perception, Geldard (1940) noted that

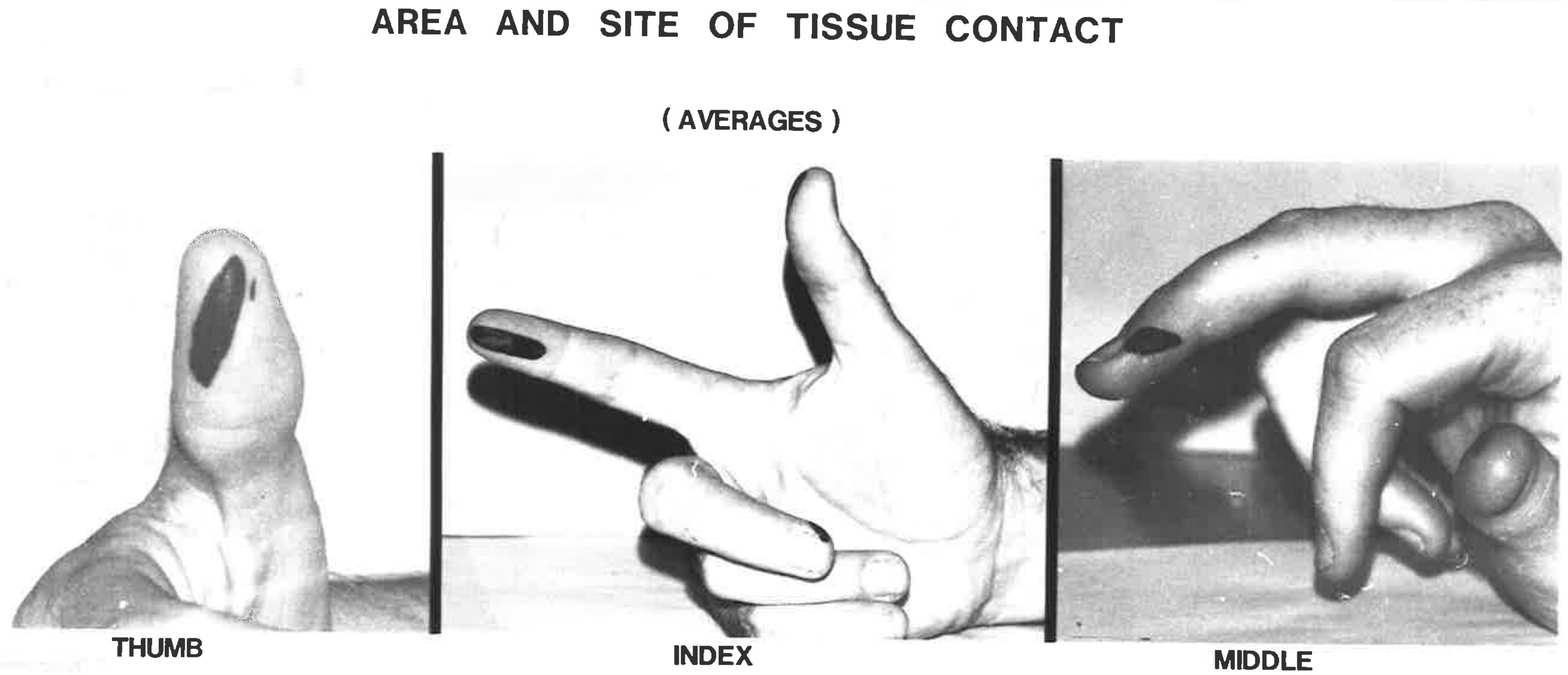
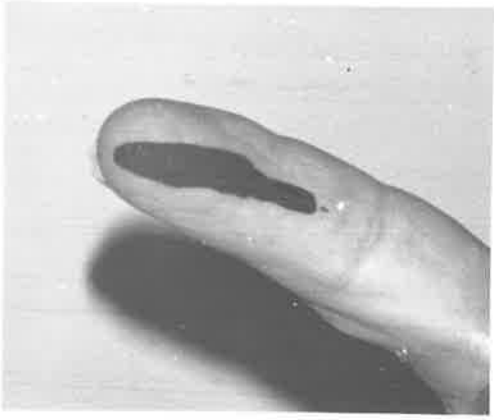


Fig. 6.2. Average area and site of finger tissue contact.



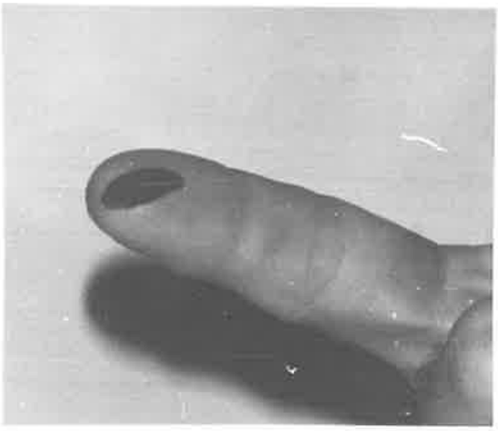
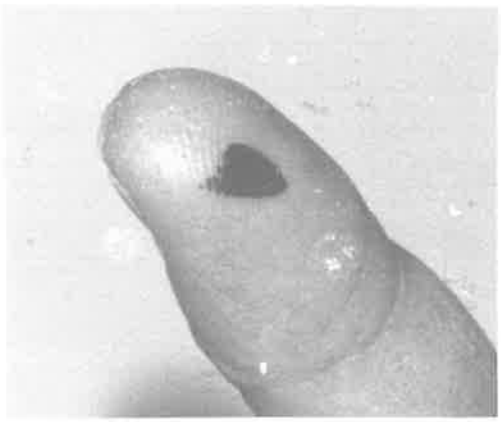


Fig. 6.3. Variations in finger contact areas on the index finger.



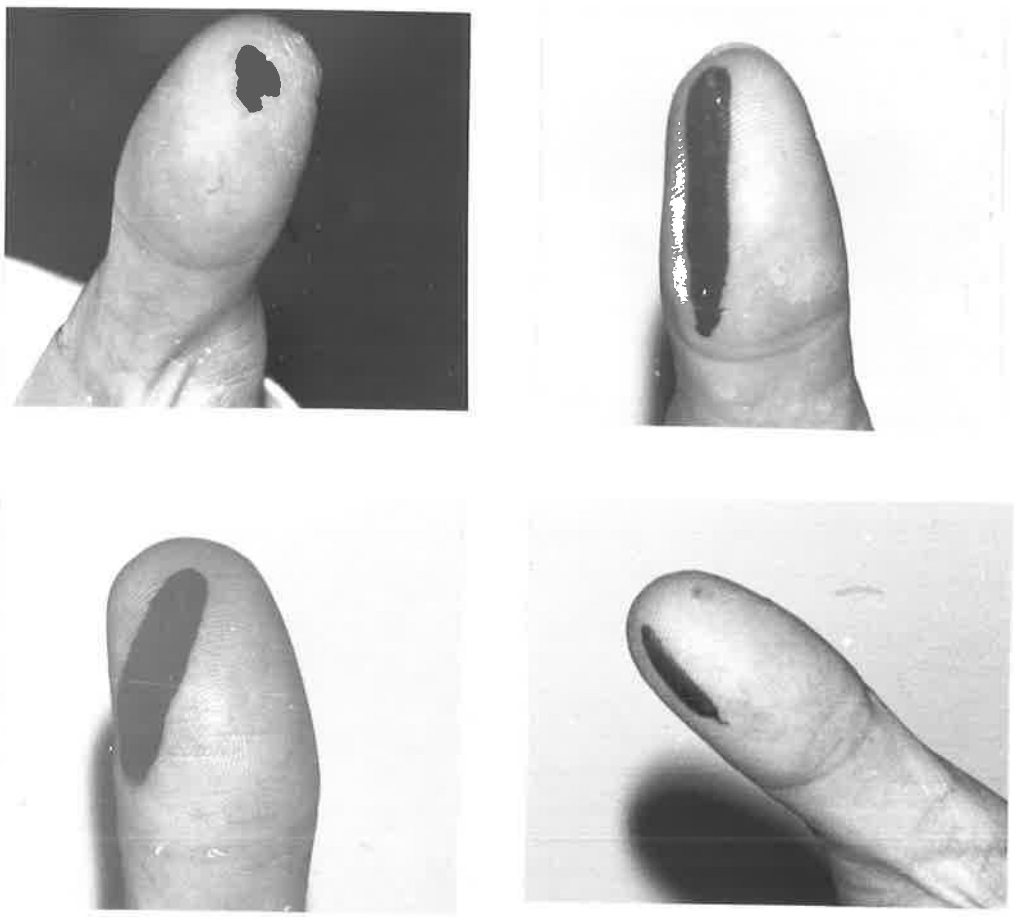
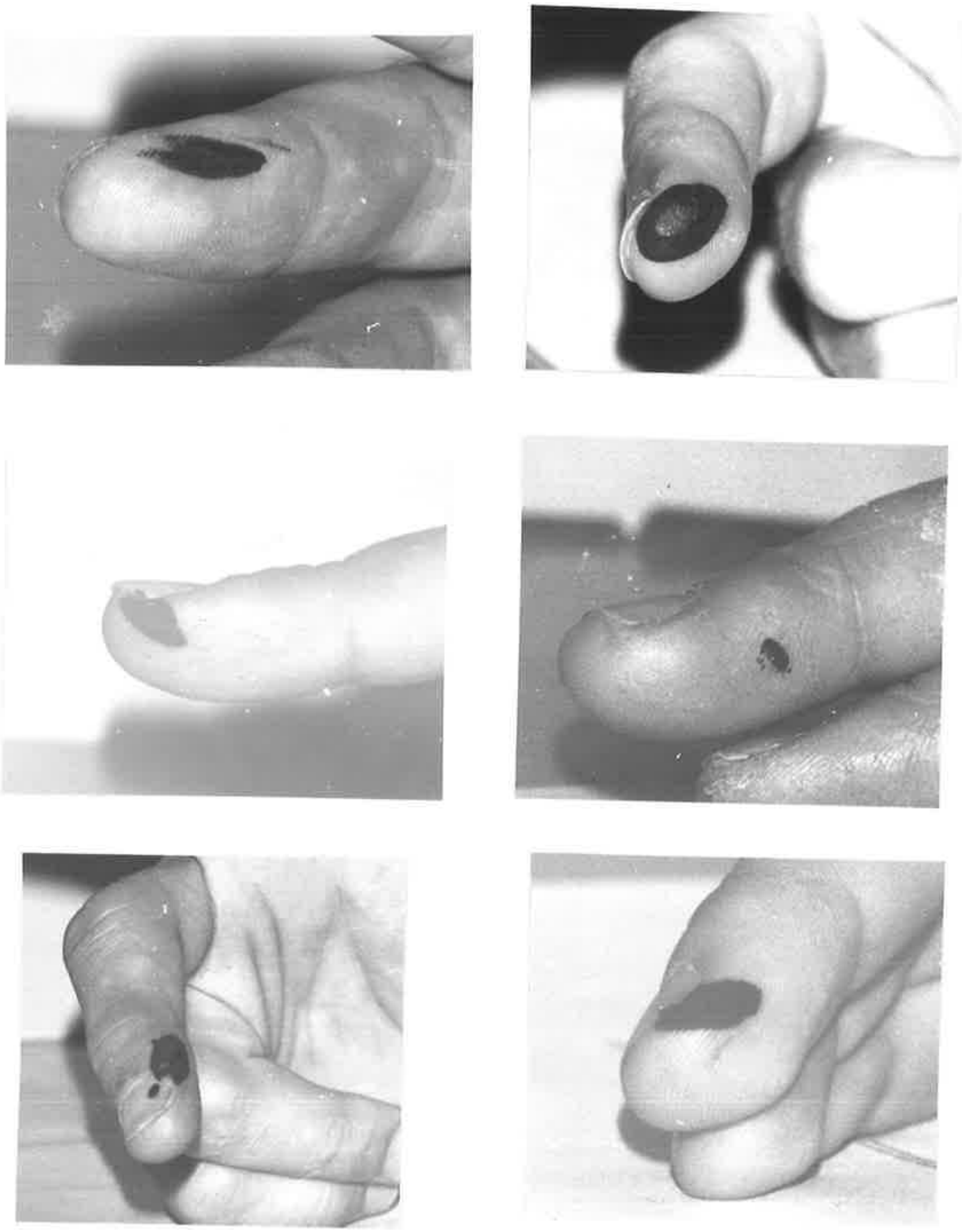


Fig. 6.4. Variations in finger contact areas on the thumb.



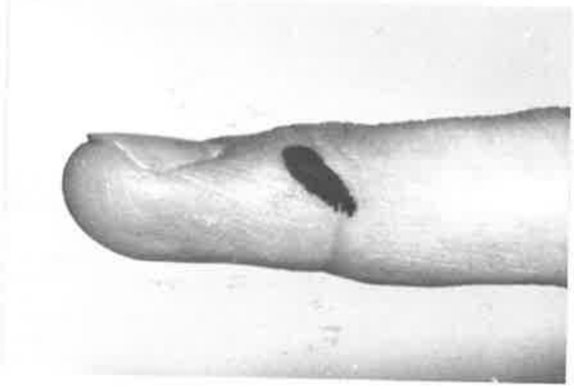


Fig. 6.5. Variations in finger contact areas on the middle finger.

vibration sensitivity was dependant on the areal extent of a stimulus. Later studies by Verrillo (1963, 1966 a and b) revealed that vibratory threshold varies with the frequency of vibration for stimulus areas one square millimeter or greater, (sensitivity being greatest near 250 Hz), and is independent of area at low frequencies. This phenomenon is attributed to the presence of a dual receptor system within glabrous skin, with one system being responsive to changes in the area of stimulation and frequency whilst the other is independent of both these parameters (VERRILLO et al, 1969).

Multiple contact areas allow for spatial summation of the vibratory stimulus. The total vibratory intensity perceived when the three finger contact areas are stimulated at the same time, is equal to the vector sum of the perceived single-finger intensities (BERGLUND et al, 1967).

Aside from the areal size, the site of tissue contact may bear some relationship to the relative density of vibratory receptors (CAUNA, 1965; WINKELMAN, 1965; BRUCE, 1980). Vibratory threshold studies undertaken by Wilska (1954) showed that the distal parts of the extremities were more sensitive than the proximal ones.

Irrespective of the actual contact area, the surrounding skin allows vibratory impulses to propagate over a much larger skin area and thus stimulate a greater number of receptors. However, Verrillo and Chamberlain (1972) felt that this was only of minor significance in the finger pad regions. Their reasons were; (1) that only a limited amount of additional free tissues is available to stimulation on the finger, (the effects of spatial summation being more pronounced only when surface waves can propagate over a wide area); and (2) the spread of surface waves from the fingertips is towards regions of the hand that have a lower receptor concentration.

One area of tissue contact with the instrument handle which was not considered in the present study is the "..... patch of skin near the apex of the cleft between the thumb and index finger over the second metacarpal bone or its adjoining phalanx" described by Patkin (1969) as an area for instrument support. In addition to steadying the instrument, this area of skin contact may contribute to the transmission of tactile and vibratory information.

6.3 DERMAL INDENTATION

The objective of this study was to measure the relative tissue tonicity of the tissue surfaces contacting an explorer handle.

6.3.1 MATERIALS AND METHODS

Forty-six operators as per the previous sections participated in this study. Tissue tonicity of the palmar surface of the thumb tip, the palmar surface of the index finger tip, and the medial surface of the middle finger tip was measured by indentation from a modified Shore Durometer meter* with an enlarged tip (Fig. 6.6). This instrument registered an arbitrary numerical scale corresponding to the degree of tissue resistance and hence the amount of indentation.

6.3.2 RESULTS

The results for tissue indentation of finger contact areas are shown in Fig. 6.7. The values for the medial surface of the middle finger tip, the palmar surface of the thumb tip, and the palmar surface of the index finger tip were 43.4 (S.D.±10.6), 12 (S.D.±6.5) and 11.5 (S.D.±5.1) respectively.

Using a student - Newman-Keuls (SNK) procedure (Sokal and Rohlf, 1969), there was no significant difference between indentation values of the palmar

* Zwich Co., West Germany

Fig. 6.6. Modified Shore Durometer meter with an enlarged tip (arrow).

TISSUE INDENTATION OF FINGER CONTACT AREAS

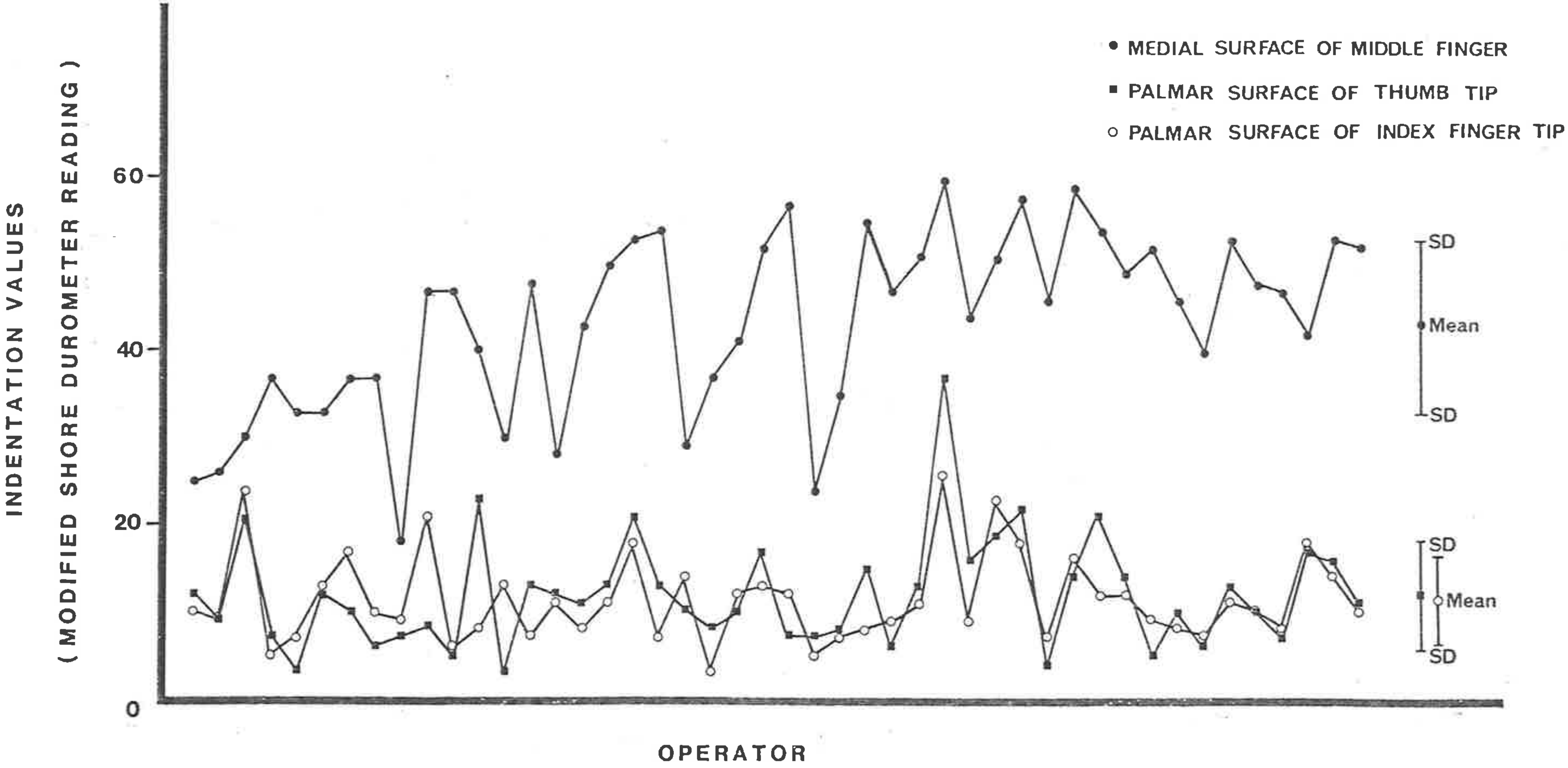


Fig. 6.7. Individual operator tissue indentation of the areas of finger contact with an explorer handle.

surface of the thumb and index fingers ($p > 0.05$), but there were highly significant differences between the indentation values of both of these surfaces and the medial surface of the middle finger ($p < 0.01$).

6.3.3 DISCUSSION

Tissue tonicity correlates well with the mechanical impedance of the skin and influences the selective transmission of vibrational stimuli to nerve receptors. In addition to determining propagation velocity, mechanical impedance functions as a filter and affects both the stimulus frequency and amplitude (KEIDEL, 1968). Finger vibration perception thresholds are directly dependent on the amount of tissue indentation (BABKIN et al, 1961; VERRILLO, 1966a).

The results of this study show that the thumb and index tissue contact areas are of the same order of magnitude of tissue compressibility, while that of the middle finger is far more resistant to displacement. The tissue components which make up the palmar surfaces of the thumb and index finger tips would be similar, but these would differ from the tissue components which make up the medial surface of the middle finger tip.

Mechanical impedance varies according to the variation in the type of tissue components which make up the total transmitting system (KEIDEL, 1968). Other factors such as skin temperature, skin blood supply and the static force on the contactor (explorer handle) influence the travelling waves in the human skin (CRAIG and SHERRICK, 1969). If the tissue is sufficiently rigid or is in close contact with bone, damping is reduced and the vibrations will spread more rapidly and over a greater distance (BABKIN et al, 1961).

6.4 EXPLORER PREFERENCE

The objective of this study was to determine explorer preferences for the evaluation of surface roughness.

6.4.1 MATERIALS AND METHODS

There were forty-six participants as for the previous studies. Explorer preference was determined by asking each operator to rate a series of seven explorers from best to worst for detecting the roughness on a standard metal roughness plate. The roughness plate used was a Rugotest plate No. 101 with a surface Ra roughness value of 0.8 um (Fig. 6.8). The same seven explorers as tested for tine rigidity in Section 5.3 were used for this study (Fig. 6.9). White noise (via headphones) was used to block any auditory feedback from the test plate. Following explorer rating by the operator a scale points system was applied.

6.4.2 RESULTS AND DISCUSSION

The results for explorer preference along with explorer tine rigidity (as determined by the dead weight test; see Section 5.3.4) are shown in Fig. 6.10.

These results show that in general the preferred explorers might be termed stiff.

The determination of explorer preference provides a guideline to carry out controlled vibration studies to evaluate the different physical characteristics between explorers. This study has already shown that one feature of preferred explorers seems to be stiff tines, and further study is warranted to determine the properties of an explorer best suited to carry out the function of surface roughness evaluation. This is further supported by the following statement from the Development and Special Products Manager of one dental instrument manufacturing company; "The majority of our products have to a large extent 'grown up like Topsy' and the satisfaction of the user has generally been a guide to manufacturing requirements" (WATSON, 1981).

The Quality Assurance Manager of another dental instrument manufacturing company wrote as follows; "The reason that we consider these hollow-handled explorers to be more sensitive is that the lower total mass of the instruments permits vibration to be transmitted to the user's hand rather than absorbed in the mass of the handle. This phenomenon is substantiated more by individual preference than by test data ..." (GUTHRIE, 1981).

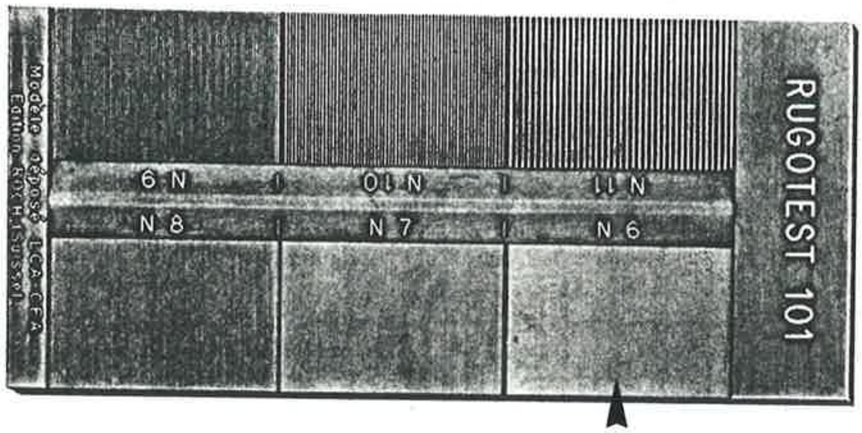


Fig. 6.8. Standard Rugotest roughness plate No. 101. (arrow) Test surface No. 32; Ra roughness value 0.8 µm.

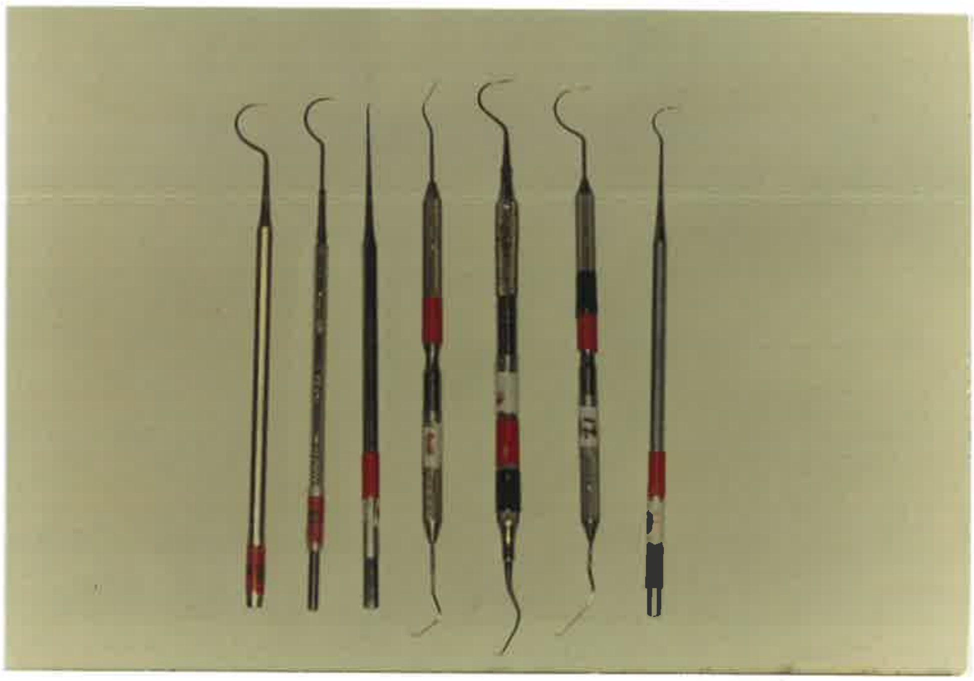
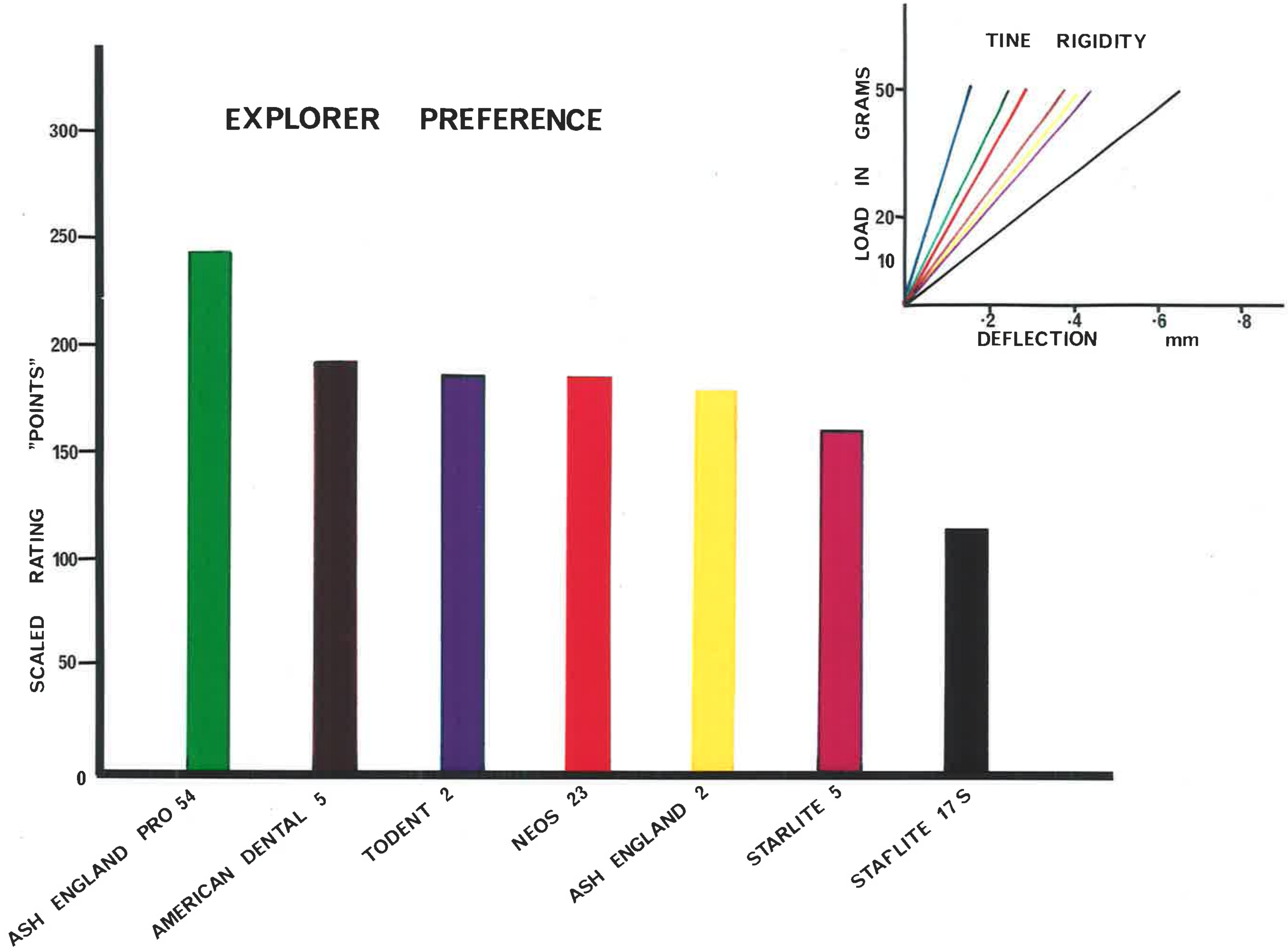


Fig. 6.9. Explorers: (from left) Ash England Pro 54, Neos No. 23, Todent No. 2, Starlite No. 17S, American Dental Amflex I No. 5, Starlite No. 5, Ash England No.2.

Fig. 6.10. Explorer preference for the evaluation of surface roughness. (top right) Explorer tine rigidity (as determined by the dead weight test; Section 5.3.4).



EXPLORER PREFERENCE
SCALED RATING "POINTS"
300
250
200
150
100
50
0
ASH ENGLAND PRO 54
AMERICAN DENTAL 5
TODENT 2
NEOS 23
ASH ENGLAND 2
STARLITE 5
STAFLITE 17 S
TINE RIGIDITY
LOAD IN GRAMS
50
20
10
·2
·4
·6
·8
DEFLECTION mm

6.5 INSTRUMENT HANDLE PREFERENCE

The objective of this study was to determine operator preference for instrument handle comfort.

6.5.1 MATERIALS AND METHODS

The preferred handle test for comfort was made with eight instrument handles in a static mode (Fig. 6.11). The forty-six operators (as for the previous study) were asked to rate the handles from best to worst and a scale points system was applied in line with operator choice.

Each operator was then asked to grip a "dough" acrylic round explorer handle form, as if to use the instrument for surface roughness evaluation, and the finger positions were held until curing of the acrylic occured (Fig. 6.12). This resulted in a handle form imprinted by the operator's fingers.

6.5.2 RESULTS AND DISCUSSION

The preferred handle test results were as indicated in Fig. 6.13 and show a preference for a round handle.

A cross-section of the "average" resultant handle form from acrylic indentation by operator finger positions is illustrated in Fig. 6.14 and is of a triangular configuration. A limitation of this exercise was holding the handle form in a passive mode which did not allow for freedom of instrument rotation. In addition, the acrylic handle form did not maintain rigidity and therefore did not offer support from the

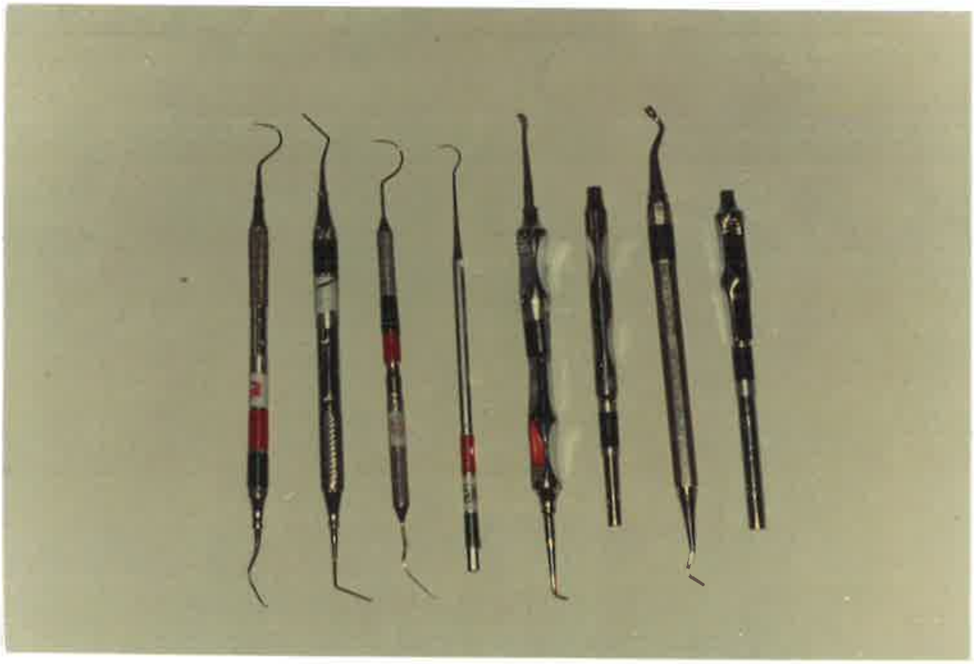


Fig. 6.11. Instrument handles: (from left) American Dental Amflex I No. 5, American Dental Amflex I No. 335, Starlite No. 5, Ash England No. 2, Dentoform, Martin (round), Hu-Friedy, Martin (square).

Fig. 6.12. "Dough" acrylic round explorer handle form held as if to use the instrument for surface roughness evaluation.

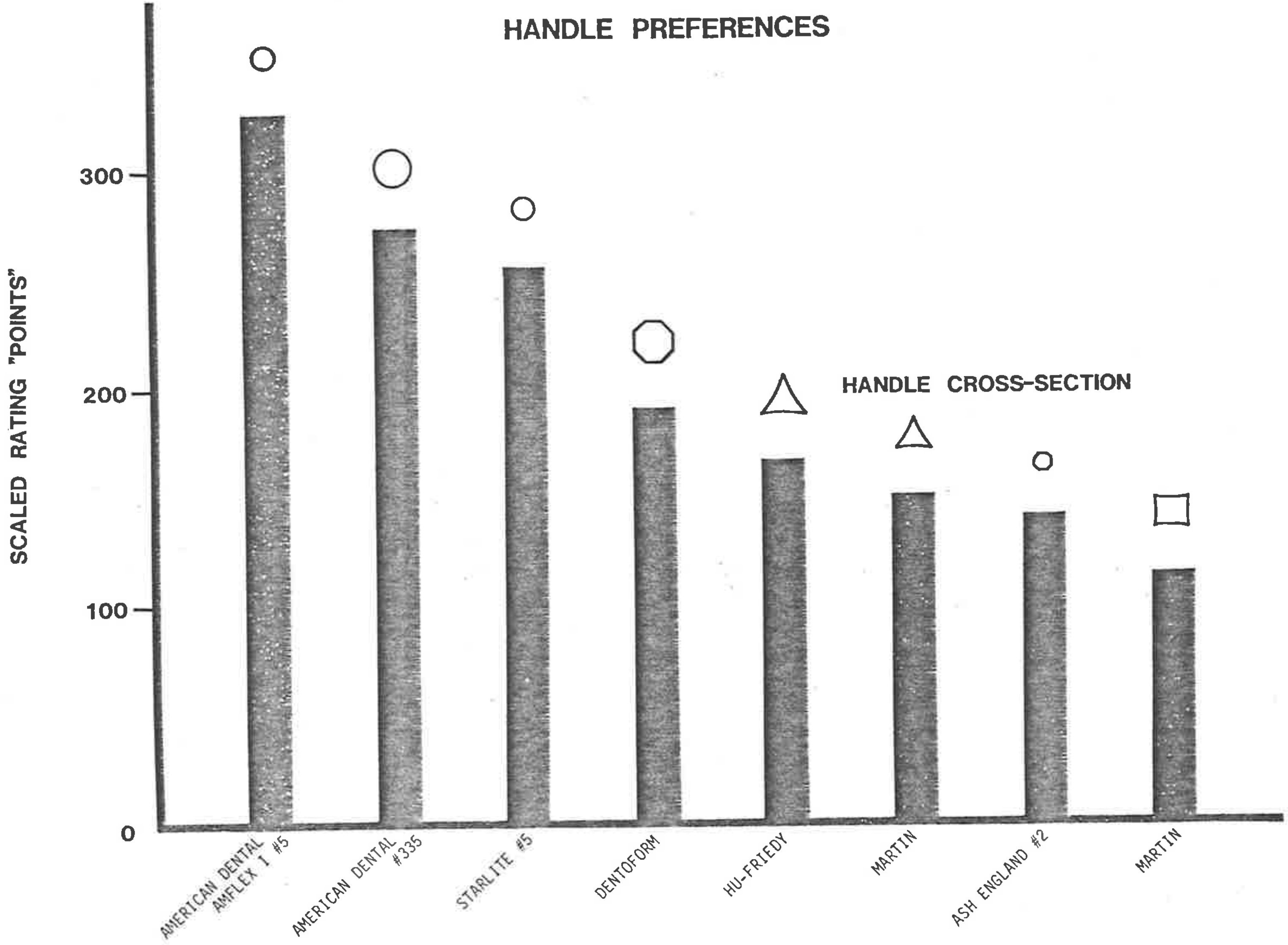


Fig. 6.13. Operator preference for instrument handle comfort.

Fig. 6.14. Cross-section of the "average" resultant handle form from acrylic indentation by operator finger positions.

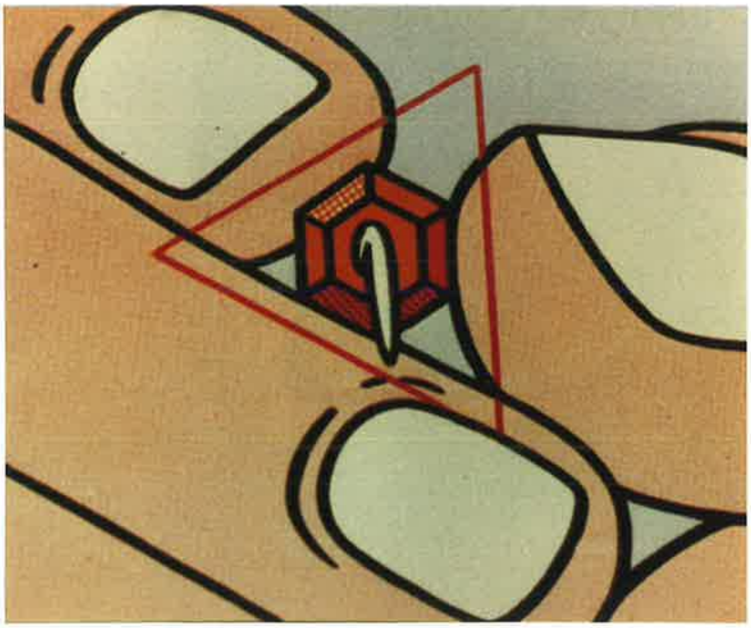


Fig. 6.15. Cross-sectional view of a Jordan dental instrument handle as displayed by the company's information literature.
(Jordan as-Oslo- Norway)

tissue area between the thumb and index finger.

Ergonomic instrument studies in the field of microsurgery define the property of rotatability of instruments as being essential for sensitive work (PATKIN, 1969, 1979; VON ZEPPELIN, 1981).

Information literature published by the Jordan dental instrument manufacturing company* emphasises the working physiology as being the basic criteria for their instrument handle design. They provide a handle which "... is without 'anatomical forms' to enable individual grips ..." (Fig. 6.15). For the classical pen grip, this manufacturing company considers the hexagonal shape to be the optimal cross-section design.

Apart from shape, other instrument handle characteristics warrant consideration. These include surface markings (knurling), weight and size. Surface markings are provided to prevent finger slippage thus securing the "grip" of the instrument. However reflection and refraction properties of waves and scattering of sound (vibration) incident on a rough boundary may theoretically indicate the need for a smooth and not serrated handle form perhaps in conjunction with a transfer gel (BROWN and SMALLWOOD, 1981).

* Jordan as, Oslo, Norway

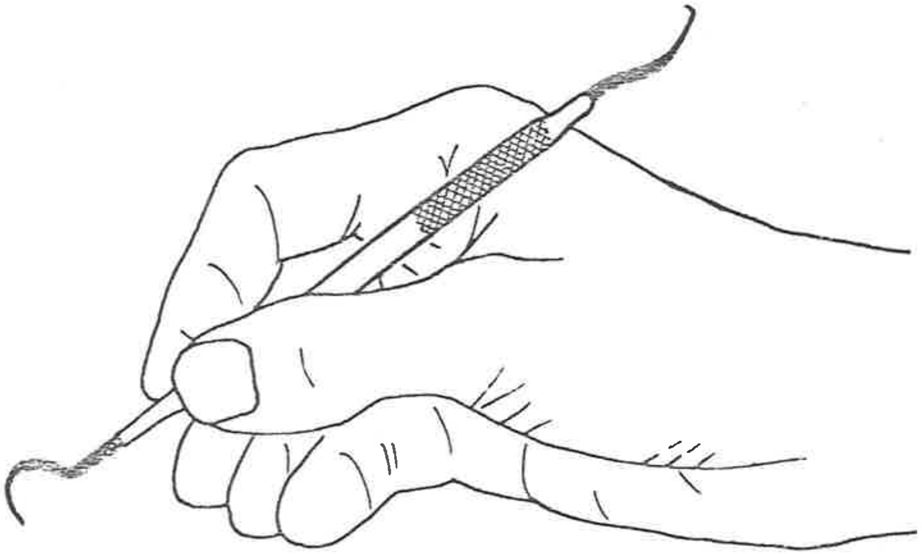
Heavier instruments tend to reduce physiological tremor (VON ZEPPELIN, 1981), whilst an increase in the overall size of the instrument handle may sometimes cause an increase in physiological tremor (PATKIN, 1979).

IN SUMMARY

Instruments with round handles were favoured by the majority of operators, but other handle characteristics aside from cross-sectional shape contribute to the overall instrument handle comfort.

CHAPTER VII

GENERAL DISCUSSION



SPECIMEN

material

roughness

- amplitude
- frequency

EXPLORER

(a) Tine

- material
- shape
- length
- density
- sharpness
- flexibility

(b) Handle

- material
- shape
- length
- density
- weight
- size
- tine junction

OPERATOR

(a) Clinical Factors

- load
- direction
- speed
- finger positions
- finger pressure

(b) Physiological Factors

- skin impedance
- CNS interpretation
- temperature
- experience
- disease
- fatigue
- drugs
- age

Fig. 7.1. Variables which affect the perception of a vibratory stimulus when using a dental explorer for the purpose of surface roughness evaluation.

CHAPTER VII

GENERAL DISCUSSION

7.1 INTRODUCTION

When using a dental hand instrument for the purpose of surface roughness evaluation, the tactile stimulus perceived is affected by the properties of the surface being examined, instrument characteristics and operator variables (Fig. 7.1).

In the previous three chapters, the detailed results were analysed and discussed in depth for surface roughness and mechanical aspects. The intention here is to relate these various findings into one inter-related whole context of perception with dental explorers.

7.2 **SPECIMEN**

Generally a rough surface is quantified by peaks and troughs of high amplitudes and short wavelengths. Surfaces characterised by long wavelengths are considered to be smooth, but wavy (LEITAO and HEGDAHL, 1981).

Different dental cutting instruments produce different degrees of surface roughness on natural and restored tooth surfaces. The use of surface roughness measuring instruments as a means of differentiating surface roughness has been described in the literature (CHARBENEAU et al, 1957; LAMMIE, 1957; FUSAYAMA et al, 1967; DENNISSON and CRAIG, 1972; GLANTZ and LARSSON, 1972; HEATH and WILSON, 1976).

In recent times the S.E.M. has also been used for surface roughness evaluation (BOYDE and KNIGHT, 1969, 1970; EICK et al, 1970; JOHNSON et al, 1971; VOLSCHANSKY et al, 1974; BOYDE, 1975; MYER and LIE, 1977; SMALES and CRAVEN, 1979; KANTER et al, 1980; WILLMANN et al, 1980; SMITH and WILSON, 1981).

The combined use of profiling instruments and S.E.M. observation has been reported by Vlacke (1973), Vlacke and Duggan (1981) and Roulet and Roulet-Mehrens (1981).

The above methods are valuable for research purposes but are impractical for use by the practitioner in clinical circumstances. At the present time, surface roughness is evaluated clinically by vision in conjunction with dental hand instruments such as dental explorers and scalers.

The present study has shown that dental explorers, when used for the purpose of surface roughness evaluation cut into that surface (dependent on its surface hardness) and thereby altered the topography of the surface instead of accurately following the surface profile.

7.3 INSTRUMENT FACTORS

7.3.1 EXPLORER TINE

Previous research relating to explorer tines has concentrated on the use of the dental explorer for the detection of caries (MILLER, 1951; IWAKURA and SHIMADA, 1978; JACKSON, 1959; CROCKER, 1975). There appears to be no report in the literature of any research attempting to characterise these intruments for the purpose of surface roughness evaluation.

The material used to manufacture tines is chosen for its ability to maintain a sharp tip whilst at the same time not being too brittle (GUTHRIE, 1981). The present study has cast doubt on the value of a sharp tine point for surface roughness evaluation, firstly because of the effects of such a tip on the surface being examined, and secondly, the surface roughness perceived using this instrument is many times smaller than the tip diameter.

It may be that a "softer" although still rigid tine material is of greater value for the purpose of surface roughness evaluation. Such a tip may help to maintain the integrity of the surface being examined. However, further research is necessary to confirm this.

Existing explorer tine designs have been determined largely by the constraints of access to the tooth surfaces being examined (CHARBENEAU et al, 1981). Dimensional tine characteristics such as length, shape and thickness will influence tine rigidity. The ability to transmit vibratory waves is dependant on the surface density and Young's Modulus of Elasticity of the material (TAYLOR, 1970). In the present study, explorers with rigid tines were preferred by the operators for assessing surface roughness.

7.3.2 EXPLORER HANDLE

Instrument handle designs have generally been derived from ergonomic studies (PATKIN, 1969, 1979; BEACH, 1973; JORDAN, 1981; VON ZEPPELIN, 1981). Instrument rotatability has been defined as an essential criterion for instrument handles.

Concerning the perception of surface roughness, factors such as density, shape, size and tine-handle junction will affect vibration transmission in the instrument handle (BROWN and SMALLWOOD, 1981). Oscillation in the handle will occur at a fixed rate determined by the stiffness and the mass, which is known as the resonant frequency (TAYLOR, 1970). Incident waves which have frequencies the same as or close to the material's resonant frequency will reinforce the vibrations developing a large amplitude of vibration and effecting an efficient transfer of vibration throughout the material.

If the handle is hollow a volume of air will be enclosed. In response to a vibratory stimulus this air behaves like a spring and will oscillate. Small volumes of air are "stiffer" and have less mass than large ones, and the stiffer the air, the higher the natural frequency of oscillation. Aside from volume, the shape and length of the body of air will also have an effect (TAYLOR, 1970).

A separate study is currently being undertaken to outline a viable method for the measurement of vibration in the instrument. The differential equation for a mass/spring system undergoing a forced vibration is as follows:

$$\text{Applied Force} = \frac{d^2x}{dt^2} + \frac{C.dx}{dt} + \frac{k.x}{m}$$

where

x	=	displacement (amplitude)
t	=	time
k	=	spring constant
m	=	mass
C	=	coefficient of damping
$C.\frac{dx}{dt}$	=	damping force

(THOMPSON, 1973).

By solving this equation through controlled experimental procedures, explorer characteristics could in theory be identified and employed to maximise the instrument's response to variation in surface roughness, within the frequency range at which the human hand is most receptive.

7.4 **OPERATOR FACTORS**

7.4.1 CLINICAL VARIABLES

The present study has defined some of the parameters involved in using some dental explorers for the purpose of surface roughness evaluation. These include the load applied to the explorer tine, the speed and direction of movement of the explorer across the surface, the finger load applied to the explorer handle and the finger positions on the explorer handle.

Although individual operator variation exists, the identification and measurement of these parameters is necessary in order to carry out controlled vibration studies to measure vibration in dental explorers.

7.4.2 PHYSIOLOGIC VARIABLES

Aside from dermal indentation for the thumb and middle and index fingers, no other physiologic operator variables were examined in the present study. The influence of the mechanical impedance of the skin on the selective transmission of vibratory stimuli to the receptors is a complex phenomenon and affects both the wavelength and wave velocity of the travelling waves (KEIDEL, 1968).

Tactile thresholds have been shown to increase with increasing age (BRUCE, 1980; THORNBURY and MISTRETTA, 1981). This has also been shown to apply to vibratory stimulus thresholds (WILSKA, 1954). However, little evidence exists which shows that dentist's skills fall off with increasing age. This may be due to the greater experience acquired with time (WYBURN et al, 1964; SINGLETON, 1978).

CHAPTER VIII

COMMENTS AND AREAS FOR FURTHER RESEARCH

CHAPTER VIII

COMMENTS AND AREAS FOR FURTHER RESEARCH

8.1 MECHANICAL ASPECTS

8.1.1 EFFECT OF EXPLORER USED ON TOOTH AND OTHER SURFACES

Further study would be necessary to determine the amount and sequence of explorer tine deflection during its use for the purpose of surface roughness evaluation. A possible method for this would be the use of strobe lighting combined perhaps with time-lapse photography.

8.1.2 TIP WEAR

1. It seems desirable to carry out further studies to evaluate if a "softer" tine material, while maintaining rigidity, would be of greater value for the purpose of surface roughness evaluation.
2. In light of the micro-surface characteristics of the American Dental Amflex I sickle explorer tine tip, bacterial adherence could be investigated and means sought to minimise bacterial transmission.

8.1.3 TINE RIGIDITY

A modification of the Tinius Olsen test method such that a lateral force would be applied to the explorer tine tip would expand the characterisation of tine rigidity.

8.2 TO ASCERTAIN THE CONDITIONS OF USE OF AN EXPLORER

1. For this study, the experimental method used to measure the load applied to a tooth by an explorer tine incorporated test specimens of dentine and enamel. These two surfaces have different hardness values, and this may have contributed to the range of variability obtained in the results. An alternative experimental procedure would be one in which a surface roughness test plate is used for the test specimens.
2. It may be possible to develop training and bio-feedback methods for teaching purposes to lower perception thresholds.

8.3 PHYSIOLOGICAL PARAMETERS

8.3.1 INSTRUMENT GRIP

Instrument grip classification would have relevance to controlled vibration studies for standardisation of vibration measurements on instrument handles.

8.3.2 AREA AND SITE OF TISSUE CONTACT

One area of tissue contact with the instrument handle which was not considered in the present study is the " ... patch of skin near the apex of the cleft between the thumb and index finger over the second metacarpal bone or its adjoining phalanx" described by Patkin (1969) as an area for instrument support.

8.3.3 EXPLORER PREFERENCE

The determination of explorer preference provides a guideline to carry out controlled vibration studies to evaluate the different physical characteristics between explorers. Further study is warranted to determine the properties of an explorer best suited to carry out the function of surface roughness evaluation.

8.4 VIBRATION TRANSMISSION

1. Currently, I am undertaking a study to outline a viable method for the measurement of vibration transmitted throughout a dental hand instrument.
2. Investigations should be carried out to determine the feasibility of using non-tactile means for evaluating surface roughness.

CHAPTER IX

CONCLUSIONS

CHAPTER IX

CONCLUSIONS

9.1 PILOT STUDY

1. Metal Rugotest plates provided standardised test surfaces in the range of roughness produced by clinical instrumentation on enamel and dentine. These surfaces of known roughness value were used for studies of perception threshold, operator instrument preferences, and vibration transmission.
2. The S.E.M. by its clarity in depth of field allowed the overall assessment of surface roughness of specimens and was selected as the method for examining explorer tine effects on tooth surfaces.

9.2 **MECHANICAL ASPECTS**

9.2.1 EFFECT OF EXPLORER ON TOOTH AND OTHER SURFACES

When using an American Dental Amflex I sickle explorer for the purpose of surface roughness evaluation:

1. The explorer tip cut into dental hard tissues and restorative materials with a degree of surface tearing, smearing and melting being apparent.
2. The explorer tip may skip across a surface indicating a periodicity of contact.
3. Originally smooth surfaces can be roughened by explorer examination.
4. Periodicity markings appear to be independent of the surface roughness.

9.2.2 TIP WEAR

1. Explorer tine tips manufactured by the American Dental Manufacturing Company demonstrate a comparatively minimal amount of wear when used across enamel and dentine surfaces as for detection of surface roughness.
2. Comparing an American Dental Amflex I sickle tine with a sewing needle showed the needle to have a smoother surface finish with a finer and more regular degree of taper.

9.2.3 TINE RIGIDITY

1. Tine rigidity testing should be carried out using a mode which reflects the clinical use of the instrument.
2. The British Standard test method does not simulate clinical conditions; the dead weight system more closely simulates the clinical use of an explorer in assessing surface roughness.
3. Consideration should be given to the formulation of two different rigidity test methods for dental explorer tines. One for surface roughness assessment, and the other for caries detection.

9.2.4 TO ASCERTAIN THE CONDITIONS OF USING AN EXPLORER FOR THE PURPOSE OF SURFACE ROUGHNESS EVALUATION

1. In general during examination of surface roughness a bio-feedback mechanism exists which regulates the load applied to the tooth, the speed, and the finger load applied to the handle.
2. The results showed great variation between individuals in the way explorers were handled:
   (a) The load under the tip ranged from 2 gm to 266 gm with 43.5% of operators preferring to move the instrument laterally (to the right).
   (b) The tip speed varied from 0.4 mm/sec to 9.3 mm/sec.

(c) Finger loads varied from 4.2 gm to 857 gm for the index finger, from 7 gm to 743 gm for the thumb and from 12.5 gm to 468 gm for the middle finger, although there was a tendency for a balance between either heavy or light finger loads for individual operators.

9.3. PHYSIOLOGICAL PARAMETERS

9.3.1 INSTRUMENT GRIP

When holding a dental explorer as if to evaluate surface roughness, 87% of the operators preferred to use a classical pen grip, 11% used the modified pen grip, and 2% used other grip forms.

9.3.2 AREA AND SITE OF TISSUE CONTACT

Whilst holding a dental explorer as if to evaluate surface roughness, the area and site of tissue contact showed individual operator variation.

9.3.3 DERMAL INDENTATION

There was no significant difference between indentation values of the palmar surface of the thumb and index fingers ($p > 0.05$), but there were highly significant differences between the indentation values of both of these surfaces and the medial surface of the middle finger ($p < 0.01$).

9.3.4 EXPLORER PREFERENCE

Generally, explorers with stiff tines were preferred for assessing surface roughness.

9.3.5 INSTRUMENT HANDLE PREFERENCE

Instruments with round handles were favoured by the majority of operators.

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